ILC tracking
Si strip + gas micropattern detectors
(“Si++” variant)

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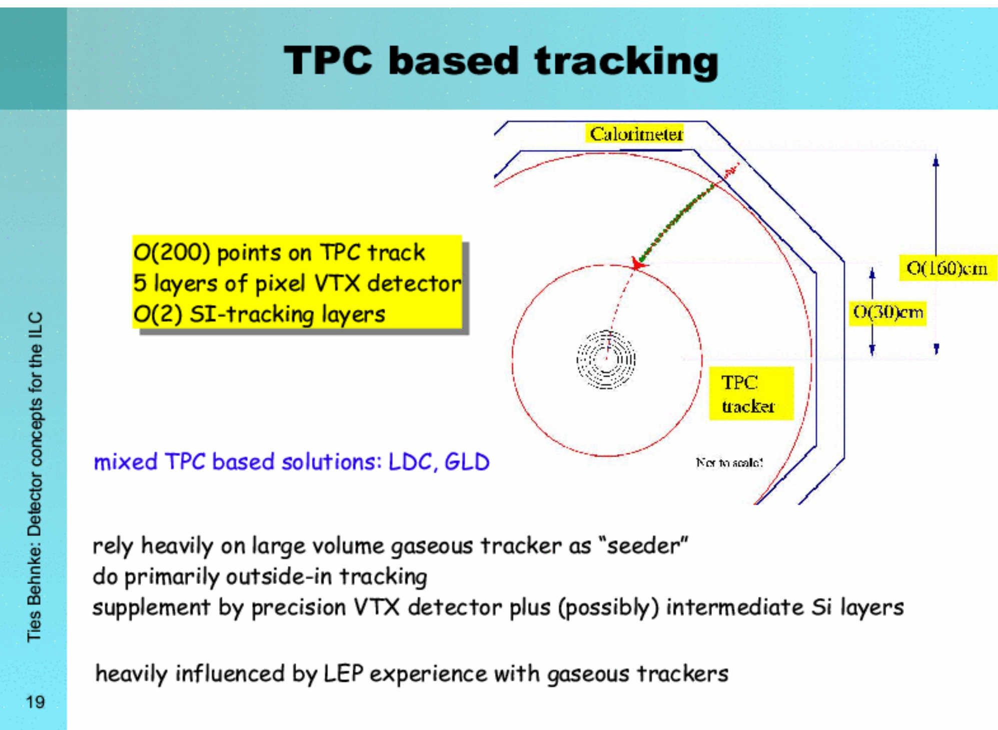
Snowmass, August 2005.

Tracking performance request and proposed variants

- track finding and reconstruction efficiency
- robust but low-mass construction
- $dPt/Pt^2 \sim 6\times10^{-5}$
- alignment, calibration

+

- Perfect track finding / pattern recognition
- Good quality Pt and Pz reconstruction
- dE/dX data



?

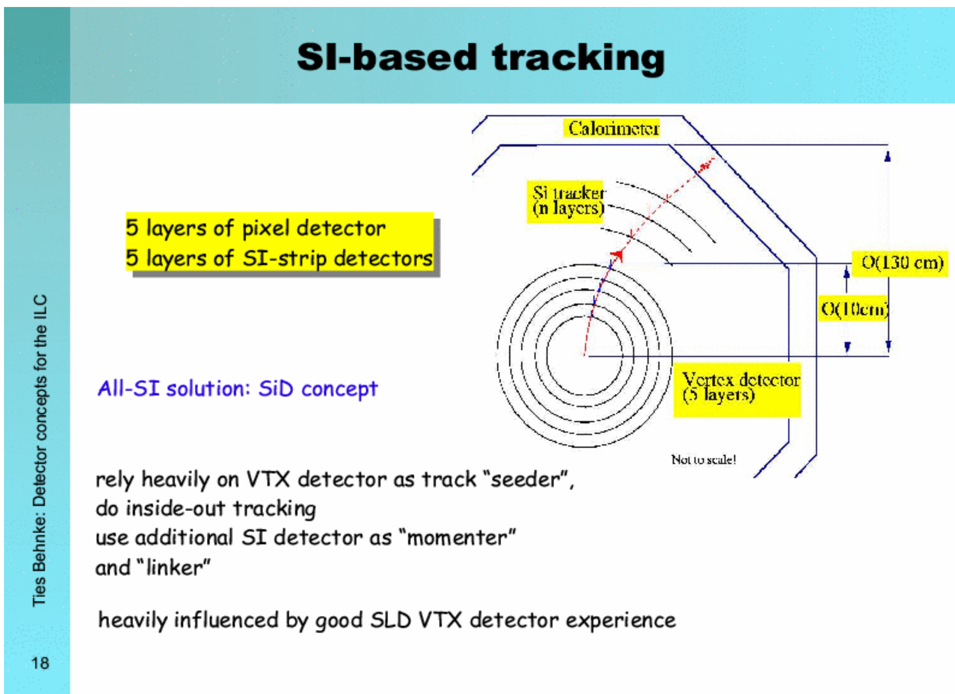
- is it realistic to get a hit space resolution ~100 μm for so long (280 cm) drift distance?
- ExB corrections / alignment (Bz >= 4 T)
- space charge distortions; F(drift distance, time structure, fluctuations)
- field cage and construction materials thickness
- membrane (cathode) HV;
  if E>350. V/cm → Vc > 100. kV

Tracking performance request and proposed variants

- track finding and reconstruction efficiency
- robust but low-mass construction
- $dPt/Pt^2 \sim 6x10^{-5}$
- alignment, calibration

\+

- Fast and reliable
- Perfect Pt reconstruction
- Compact set-up



?

- Track finding and pattern recognition
- Rely on VXD or EMC data / performance
- Pz, track matching performance

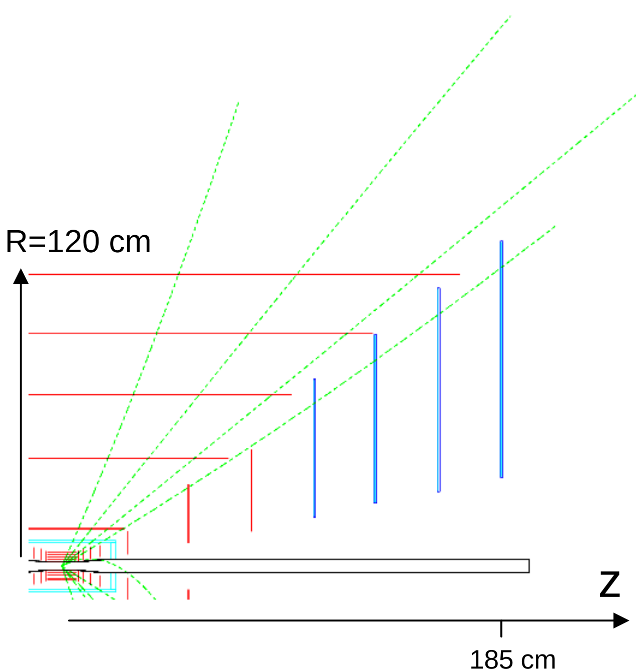
SiD and VXD in GEANT

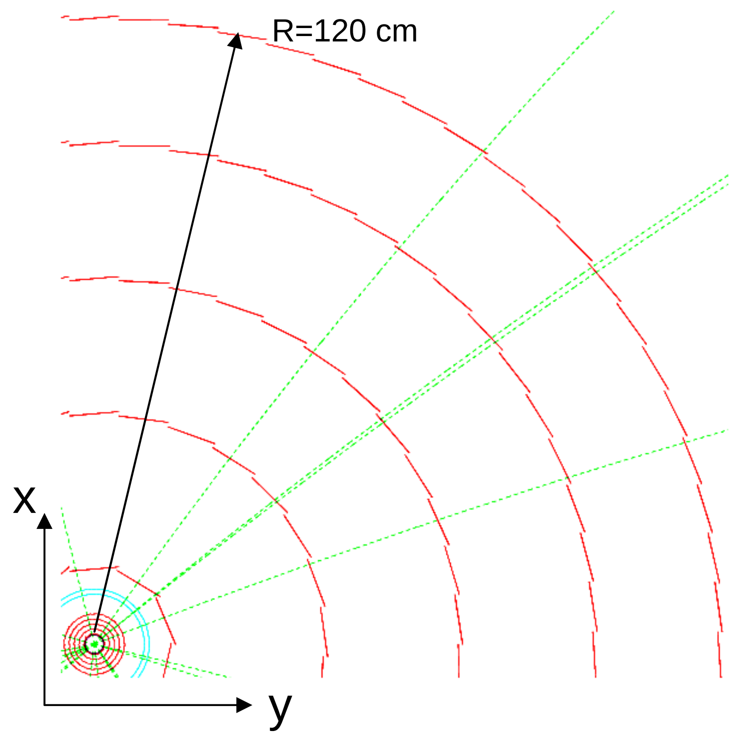
In Barrel:

Si-strip detectors: single-sided, 300 μm thickness, 10x10 cm^2 size

Si-pixel (CCD, APS, …): 100 μm thickness, 20x20 μm^2 pixel size

no construction materials, FEEs, Cables, ….





In Forward Direction:

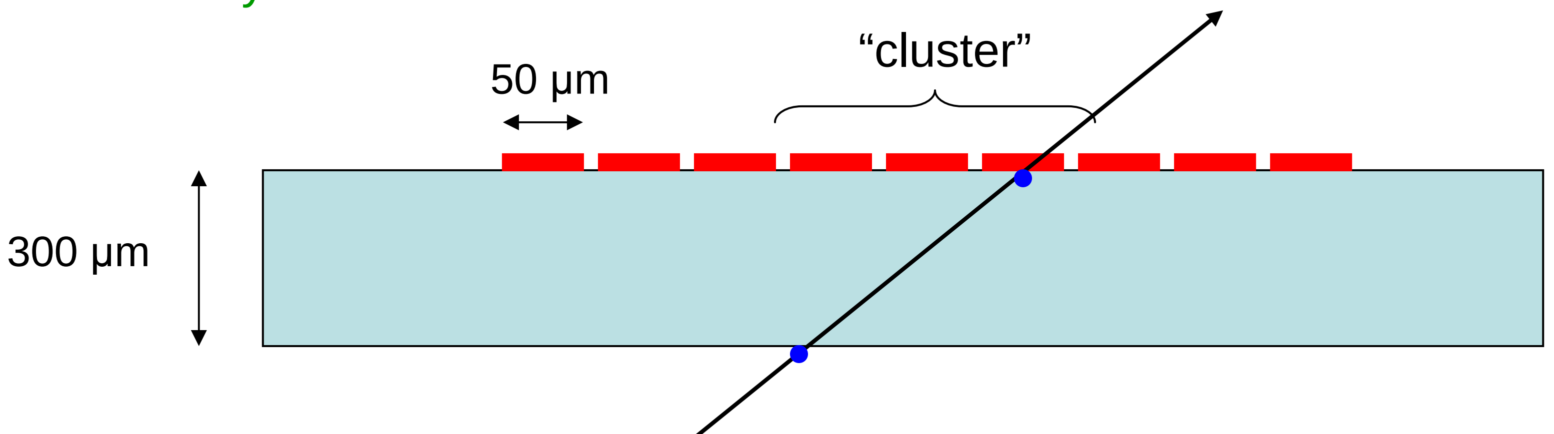
Si-strip detectors, double-sided with stereo angle

Triple GEM detectors (TGEM) with stereo-strip readout, E||B

Simulation steps

- One particle (π) per event
- Bz = 4 T
- Primary Vertex is in a Fit

1. ● - GEANT hits (points in a space)



2 - Interaction probability
- Position along the track
- Energy transferred
- Te^-, Range, Ne^-
- Diffusion, drift time
- Q on strip (pad)
- Noise, FEE response

3 Cluster finding
Hit position reconstruction (CG or η–algorithm)

The same approach for TPC response simulation

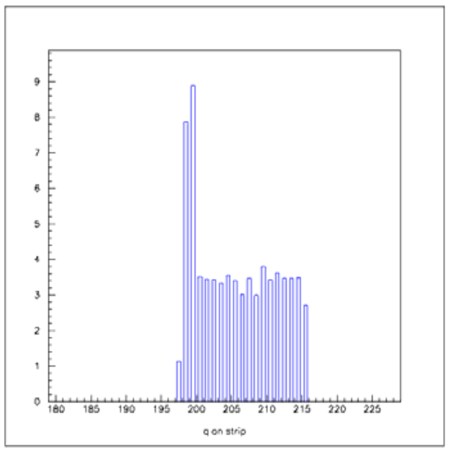
For "CCD" simulation – pad selection

For TGEM gas detectors – hits smearing

4 Helix Fit; Pt, Pz, DCAxy, rz

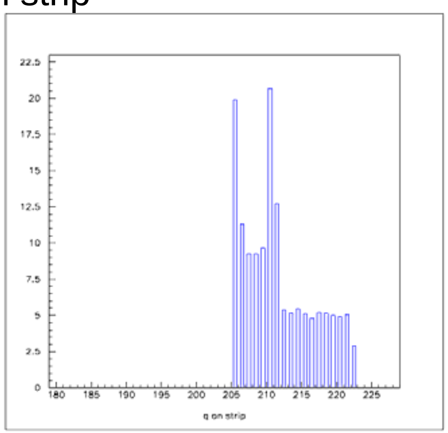
Si-strip, 50 µm pitch, hit position resolution

Q on strip



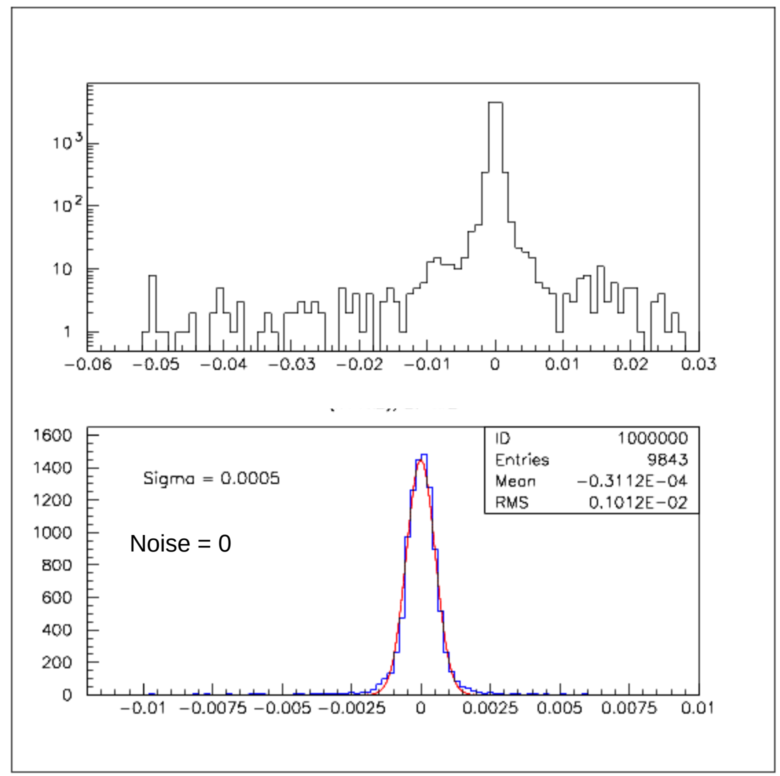
Strip N

Q on strip



Strip N

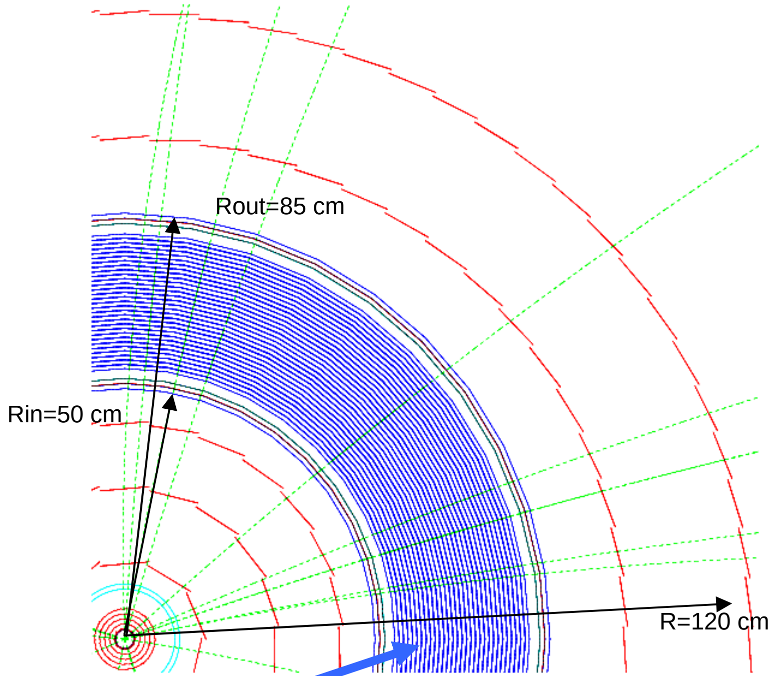
5 layers → sometimes 4 hits;
efficiency, δ-electrons, broken or “dead” channels, Lorentz angle, ….

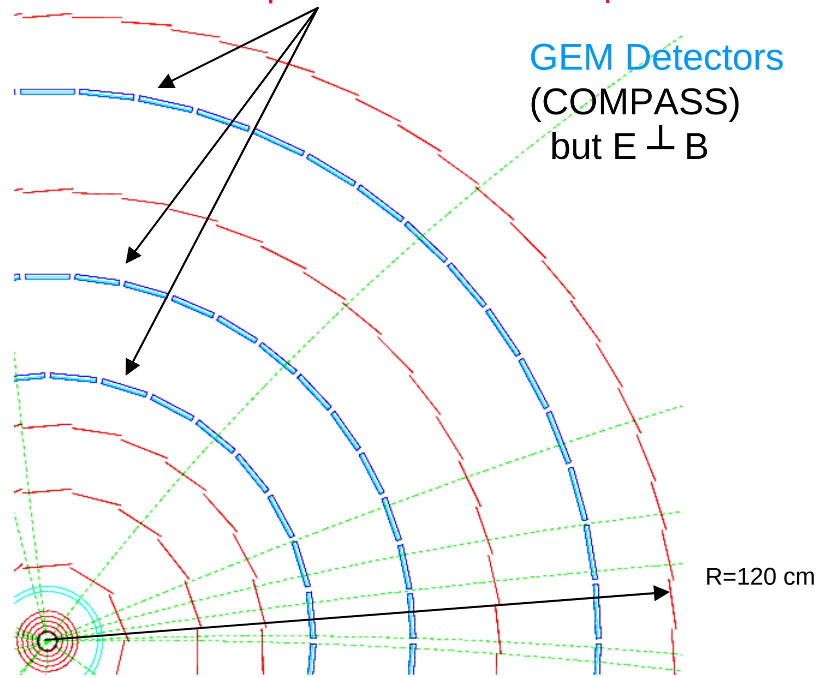


Hit; simulated – reconstructed, cm

PLUS miniTPC or triple GEM detectors with stereo-strip readout

-Gas micro-pattern strip (stereo) detectors demonstrated very good performance
-Low mass (and cost), fast, reliable, with space resolution ~40 μm

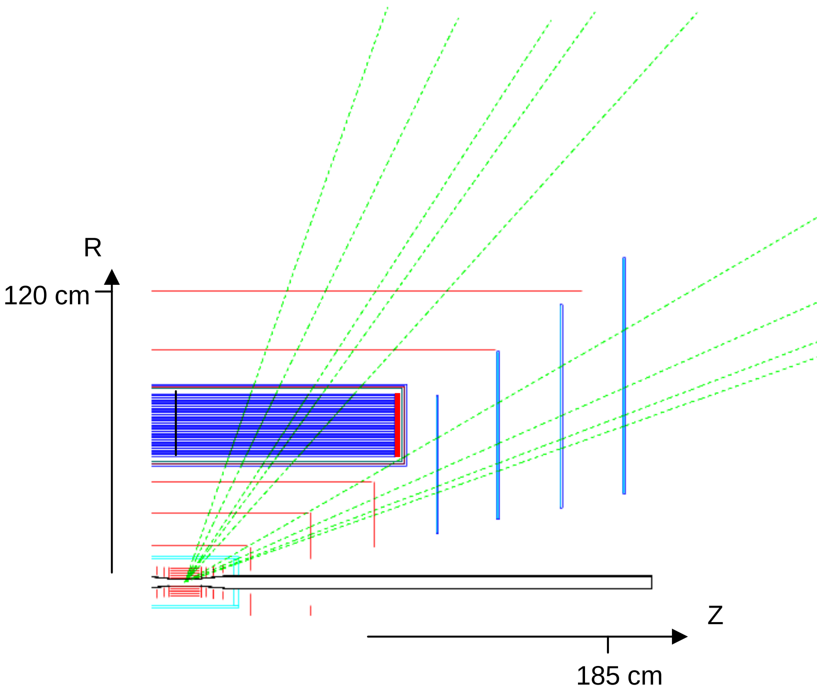


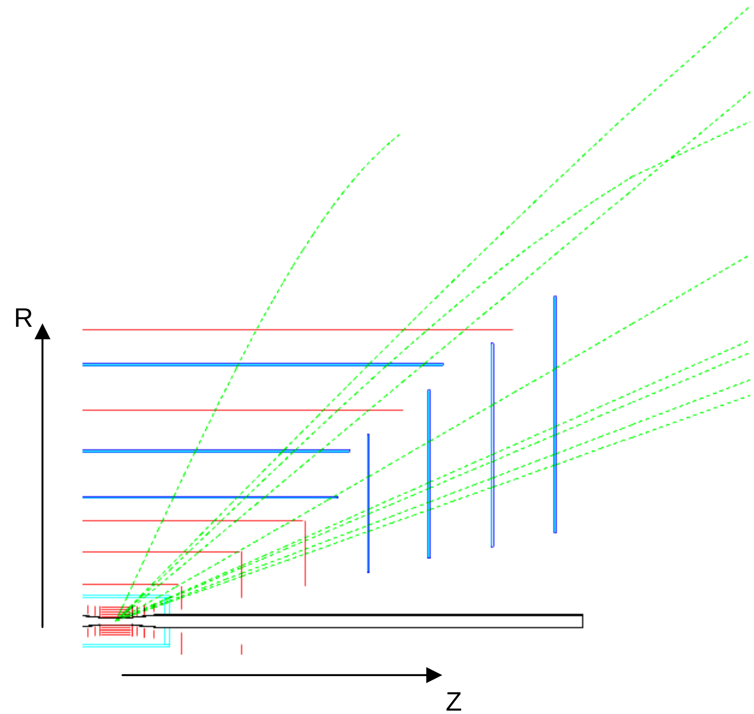


miniTPC:

- micropattern readout, 30 pad-rows, max drift distance: ~90 cm.
- fast, low diffusion “working” gas, max drift time: ~10 μs.
- low-mass construction: “no wires – no frame”, field cage and gas windows are different parts

PLUS miniTPC or triple GEM detectors with stereo-strip readout





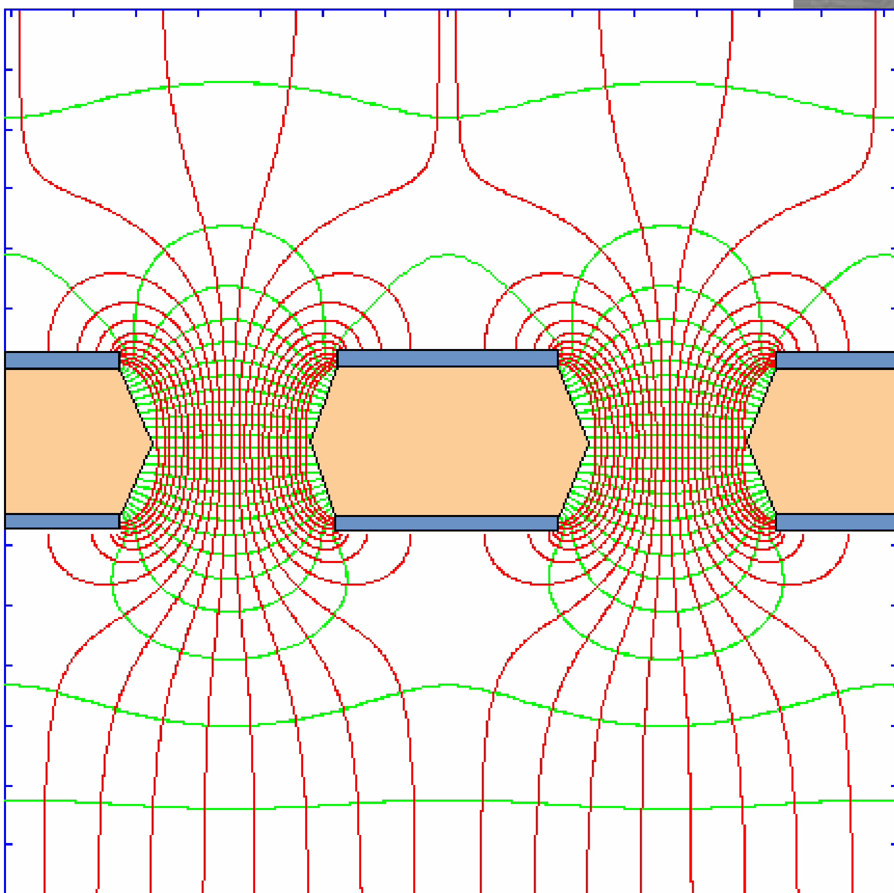
N of FEE channels:

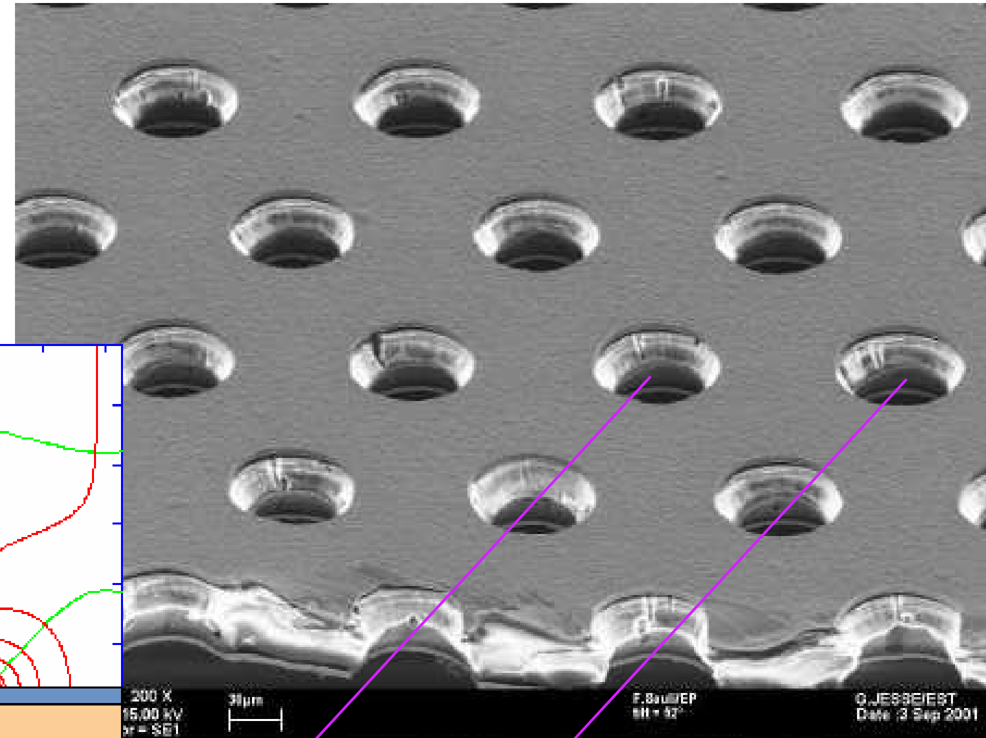
TPC: 30 pad-rows, 0.8x0.2 cm^2 read-out pad
→ ~1.2 x 10^5

Barrel; TGEM with stereo-strip read-out, 400 μm pitch, 10x10, 10x10, 20x20 cm^2 detector size
→ ~1.3 x 10^6

GEM

Thin, metal-coated polymer foil with high density of holes:





100÷200 µm

Typical geometry:
5 µm Cu on 50 µm Kapton
70 µm holes at 140 mm pitch

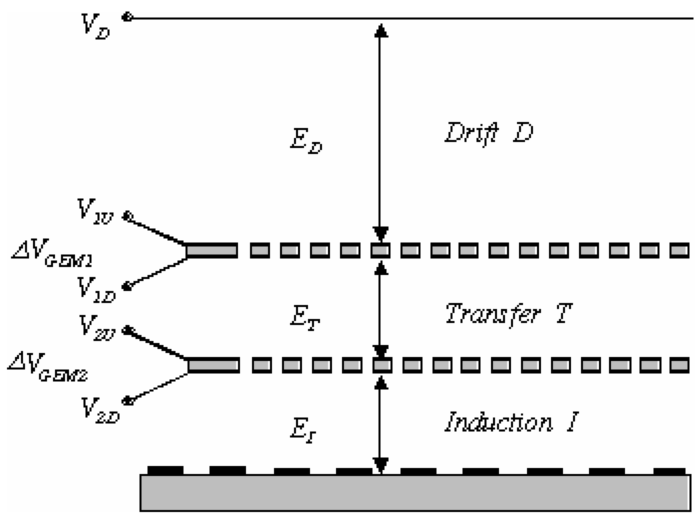
F. Sauli,
Nucl. Instrum. Methods A386(1997)531

From F. Sauli presentation

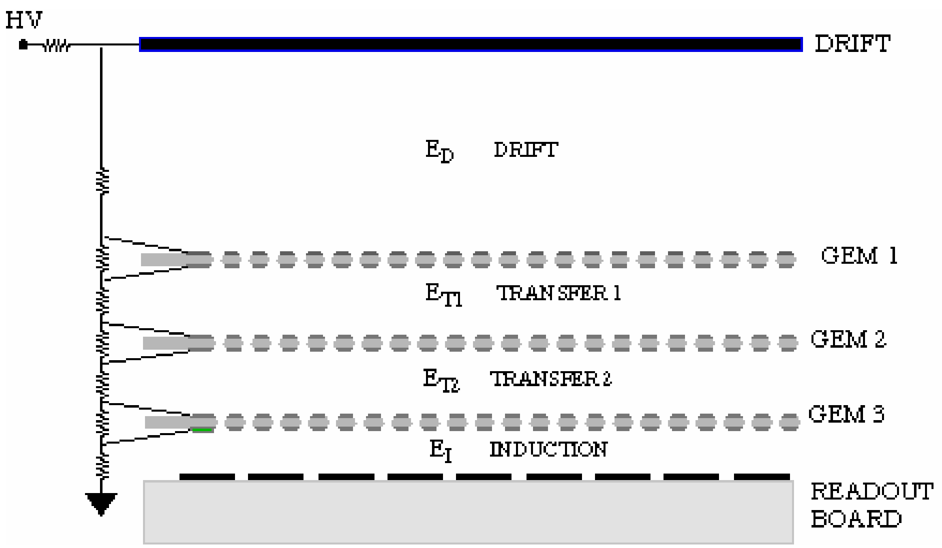
MULTIPLE GEM STRUCTURES

Cascaded GEMs permit to attain much larger gains before discharge

Double GEM



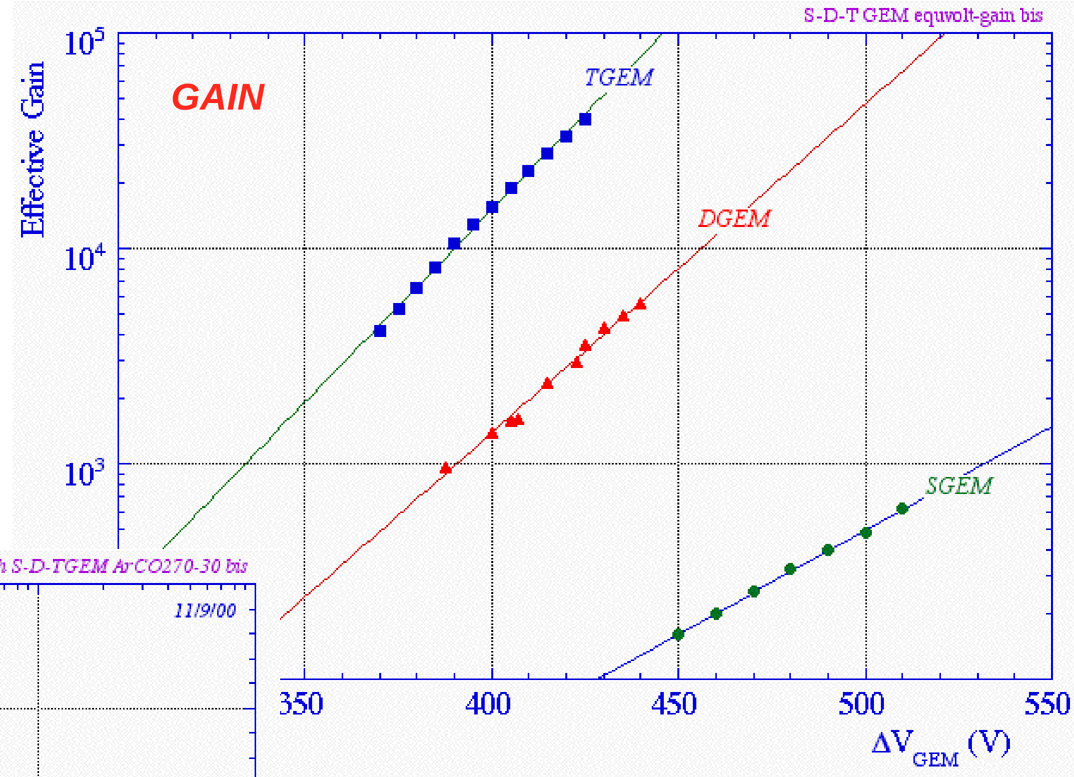
Triple GEM



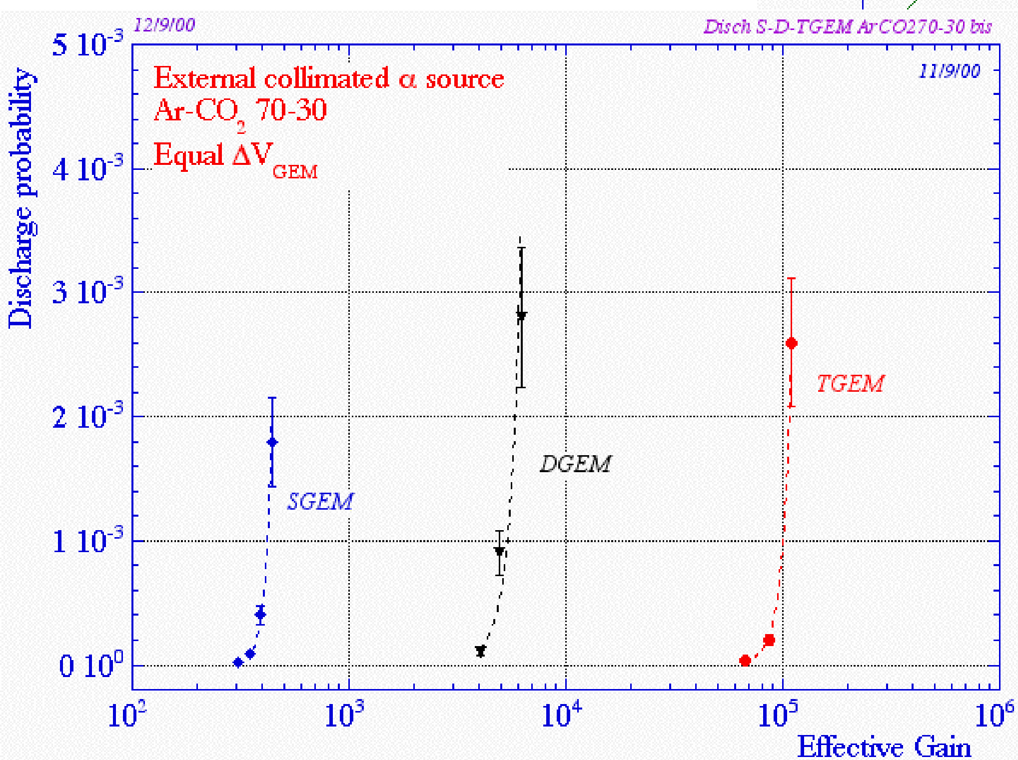
C. Buttner et al, Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464

From F. Sauli presentation

Multiple structures provide equal gain at lower voltage
The discharge probability on exposure to a particles is strongly reduced



DISCHARGE PROBABILITY WITH α-particles



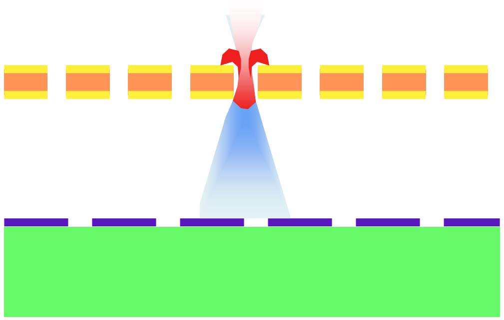
For a gain of 8000 (required for full efficiency on minimum ionizing tracks) in the TGEM the discharge probability is not measurable.

S. Bachmann et al,
Nucl. Instr. and Meth. A479 (2002) 294

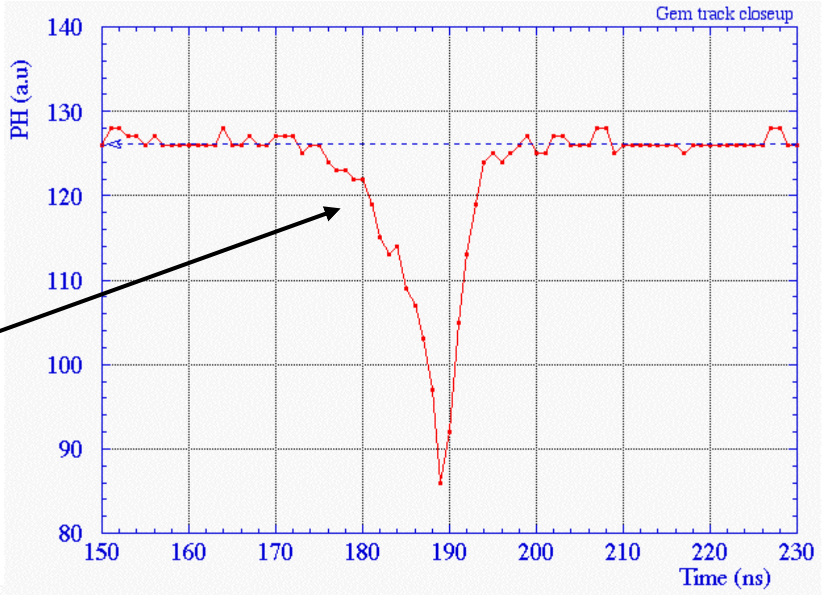
From F. Sauli presentation

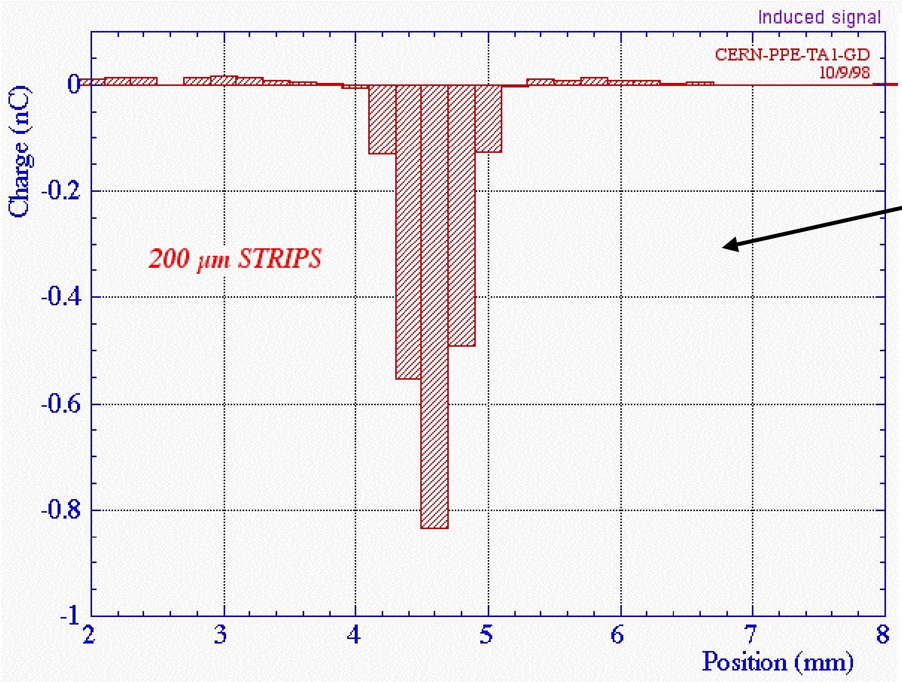
FAST ELECTRON SIGNAL (NO ION TAIL)

The total length of the detected signal corresponds to the electron drift time in the induction gap:



Full Width 20 ns (for 2 mm gap)





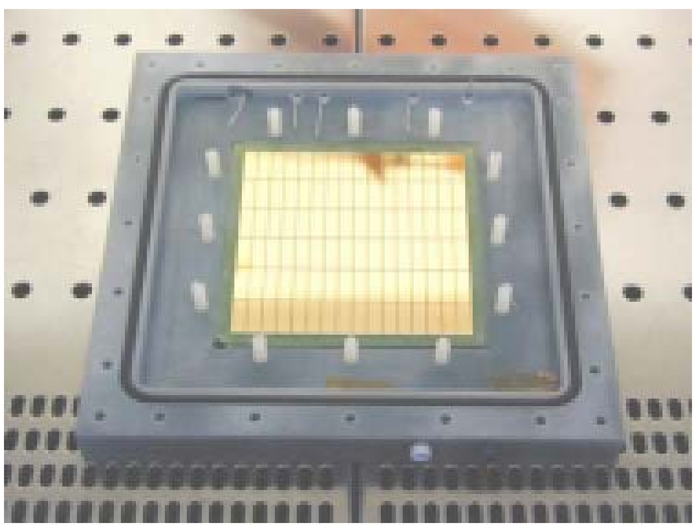
Induced charge profile on strips
FWHM 600 μm

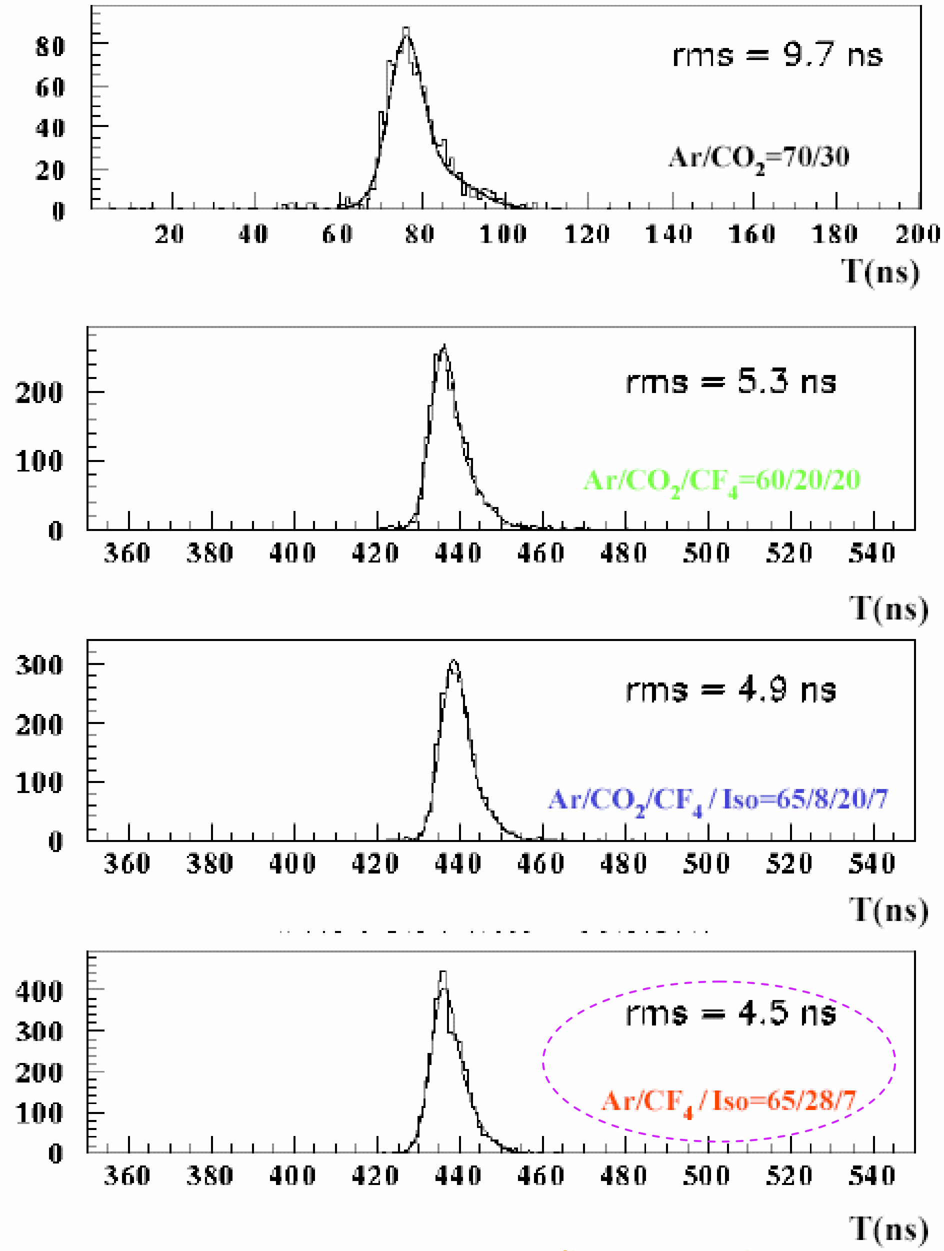
Good multi-track resolution

From F. Sauli presentation

GEM time resolution

Triple GEM with pad readout for LHCb muon detector



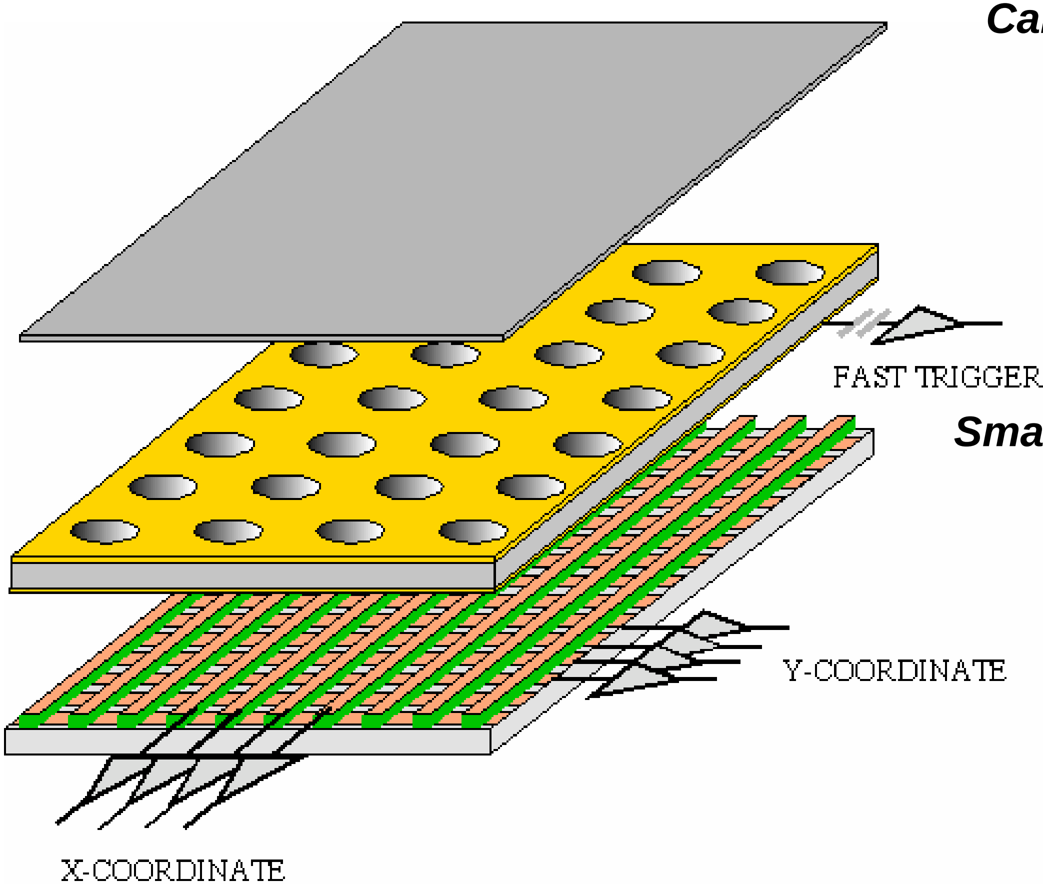


G. Bencivenni et al, Nucl. Instr. and Meth. A478(2002)245

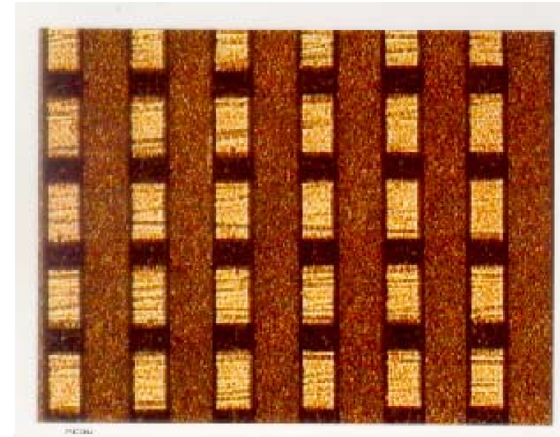
From F. Sauli presentation

GEM DETECTOR:

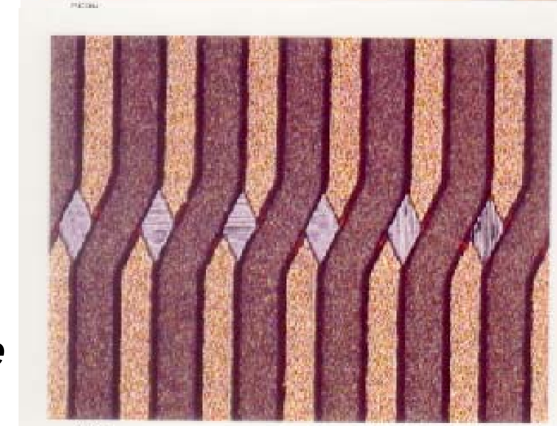
- ***multiplication and readout on separate electrodes***
- ***electron charge collected on strips or pads: 2-D readout***
- ***fast signal (no ion tail)***
- ***global signal detected on the lower GEM electrode (trigger)***



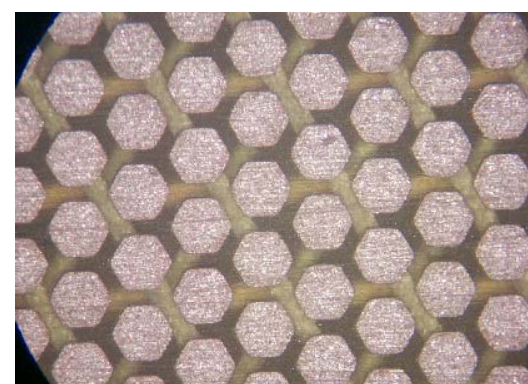
Cartesian



Small angle



Pads

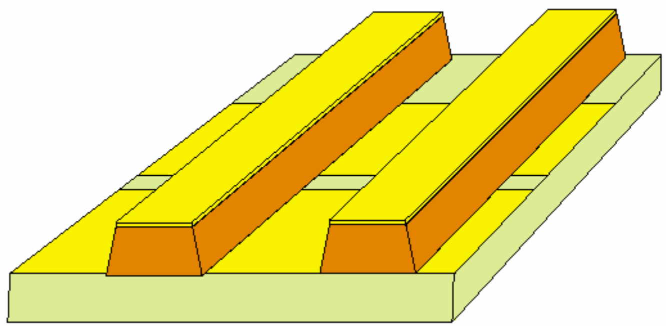


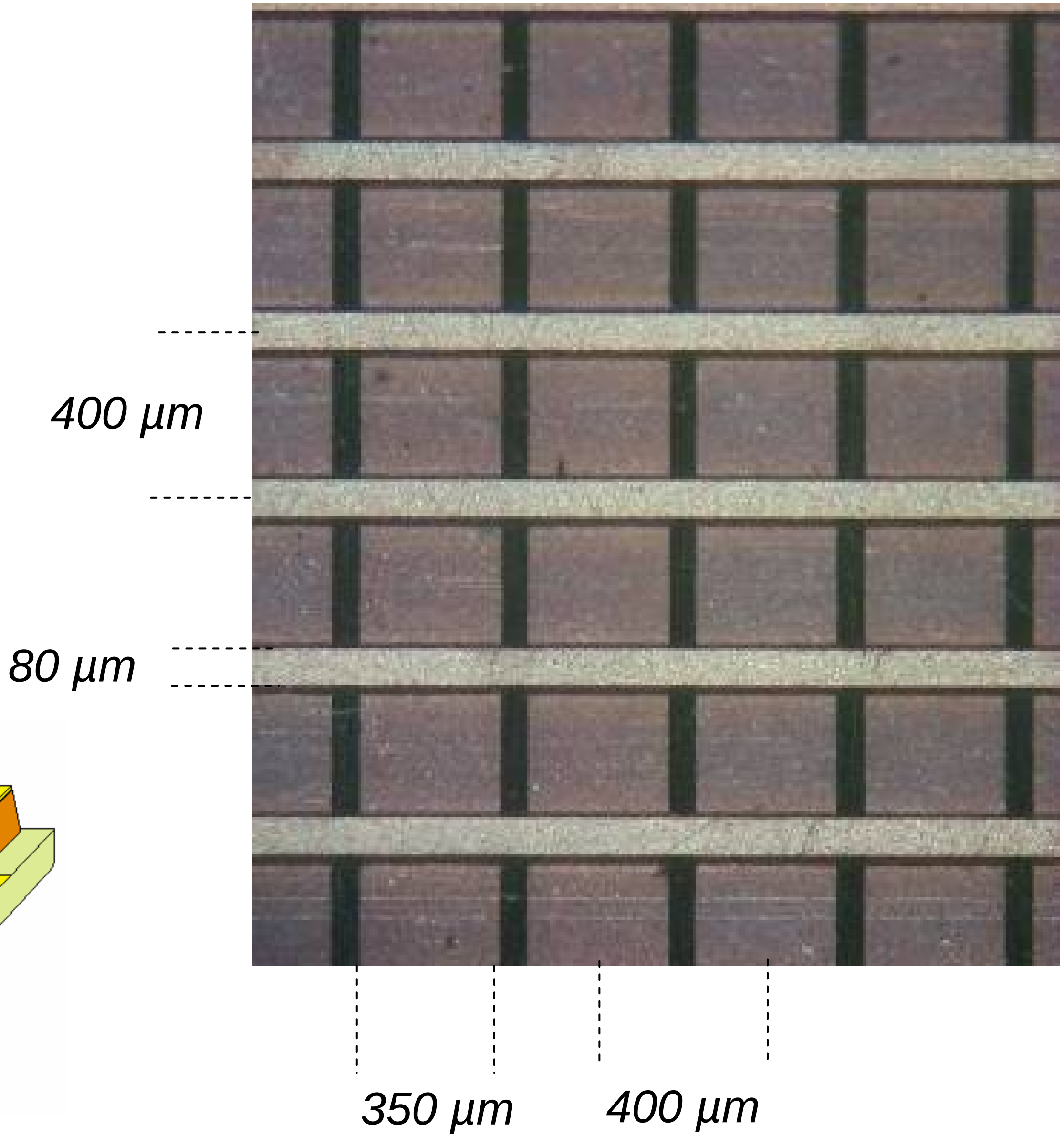
A. Bressan et al, Nucl. Instr. and Meth. A425(1999)254

From F. Sauli presentation

2-DIMENSIONAL READOUT STRIPS

Two orthogonal sets of parallel strips at 400 µm pitch engraved on 50 µm Kapton 80 µm wide on upper side, 350 µm wide on lower side (for equal charge sharing)

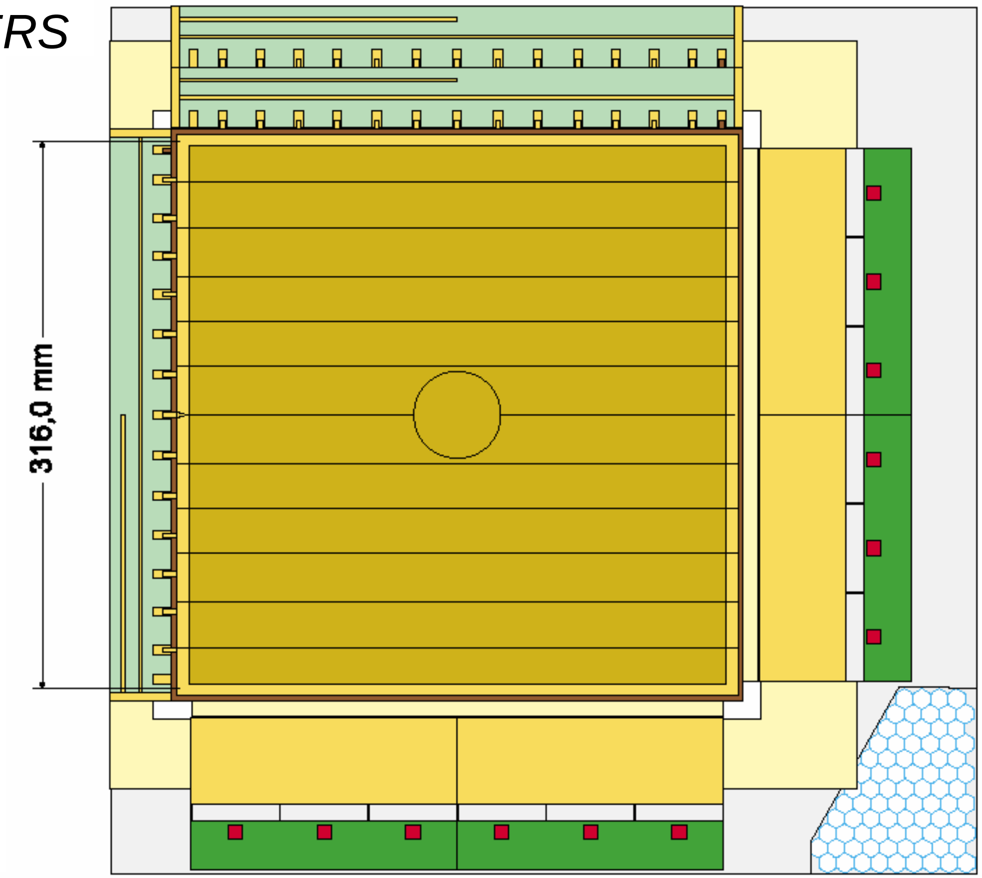


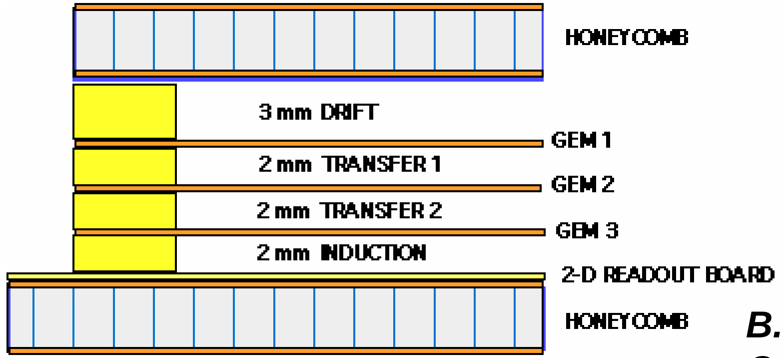


From F. Sauli presentation

COMPASS TRIPLE GEM CHAMBERS

- Active Area 30.7 x 30.7 cm^2
- 2-Dimensional Read-out with
  2 x 768 Strips @ 400 µm pitch
- 12+1 sectors GEM foils
  (to reduce discharge energy)
- Central Beam Killer 5 cm Ø
  (remotely controlled)
- Total Thickness: 15 mm
- Low mass honeycomb support plates

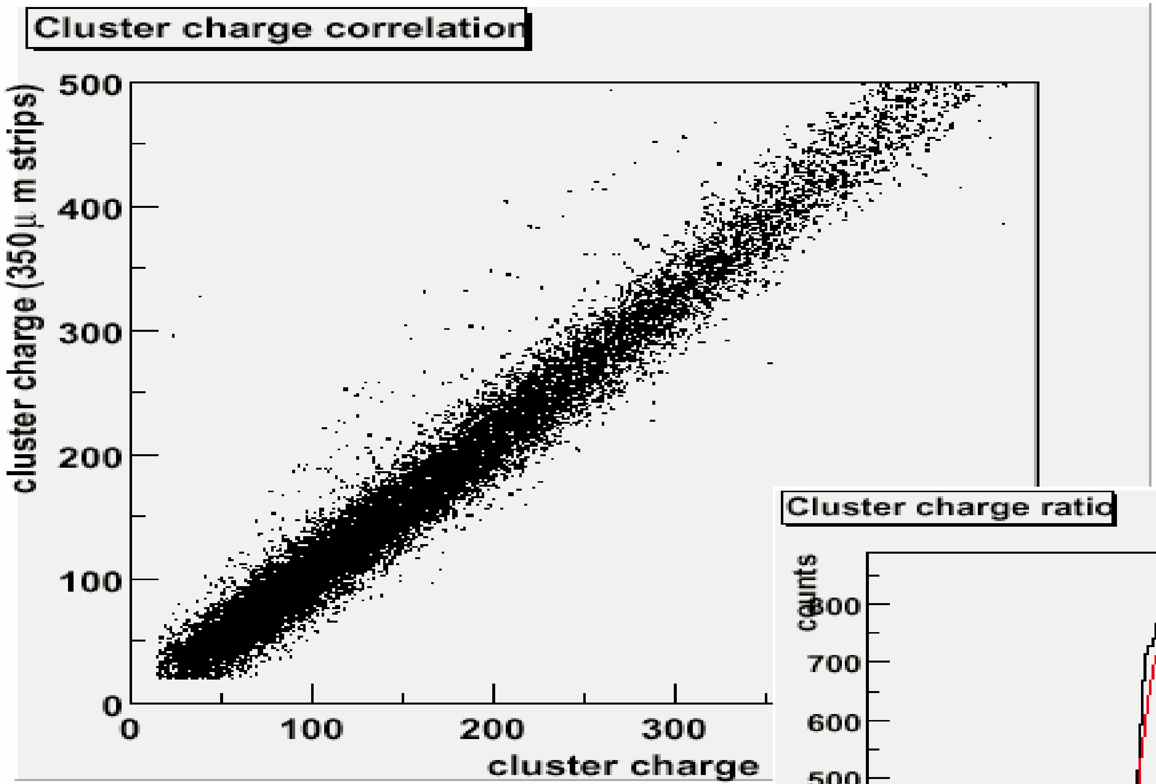




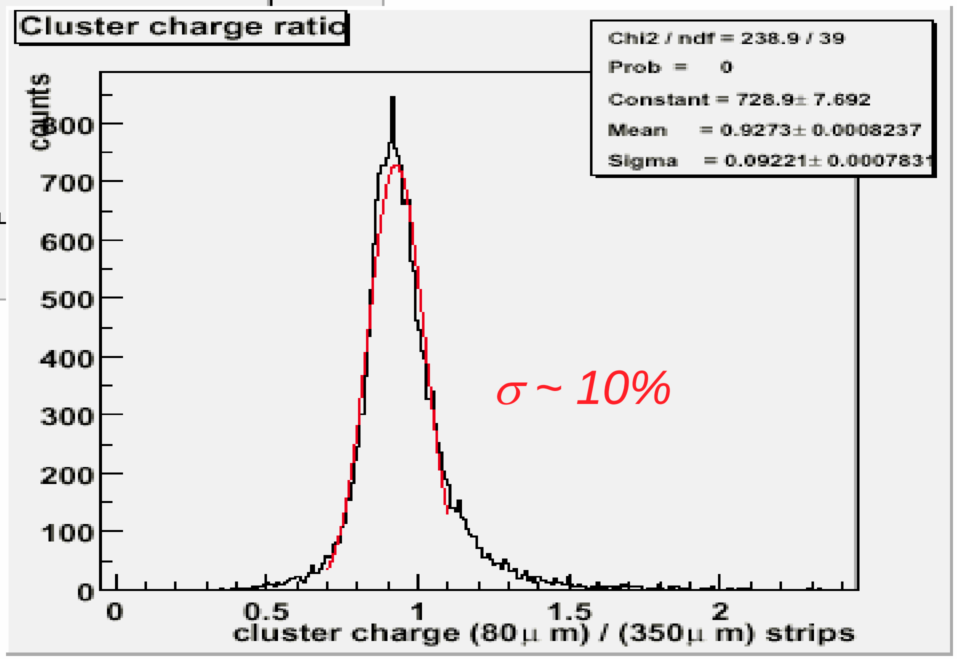
B. Ketzer et al, IEEE Trans. Nucl. Sci. NS-48(2001)1065
C. Altumbas et al, Nucl. Instrum. Methods A490(2002)177

From F. Sauli presentation

CLUSTER CHARGE CORRELATION



Very good correlation, used for multi-track ambiguity resolution

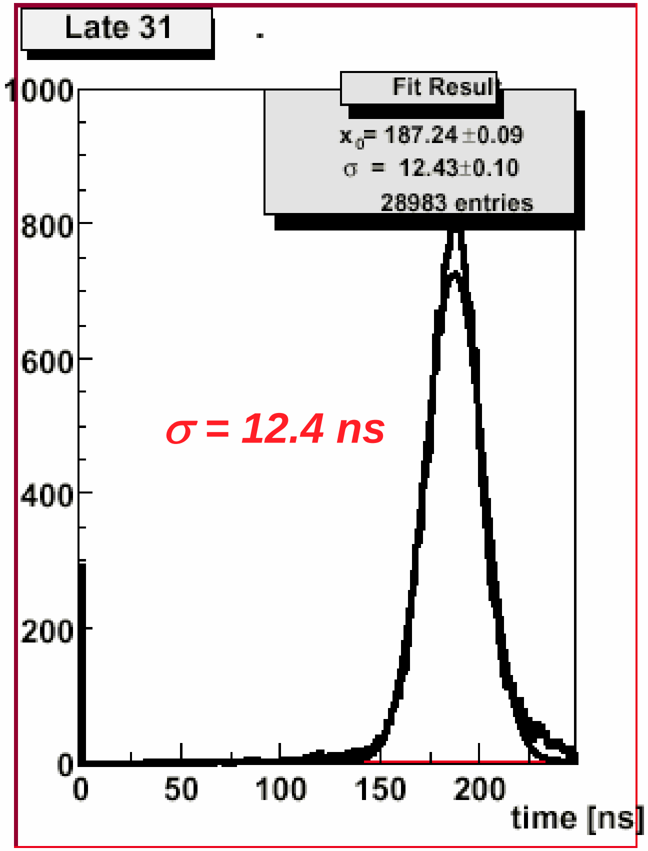


X-Y Cluster charge correlation:

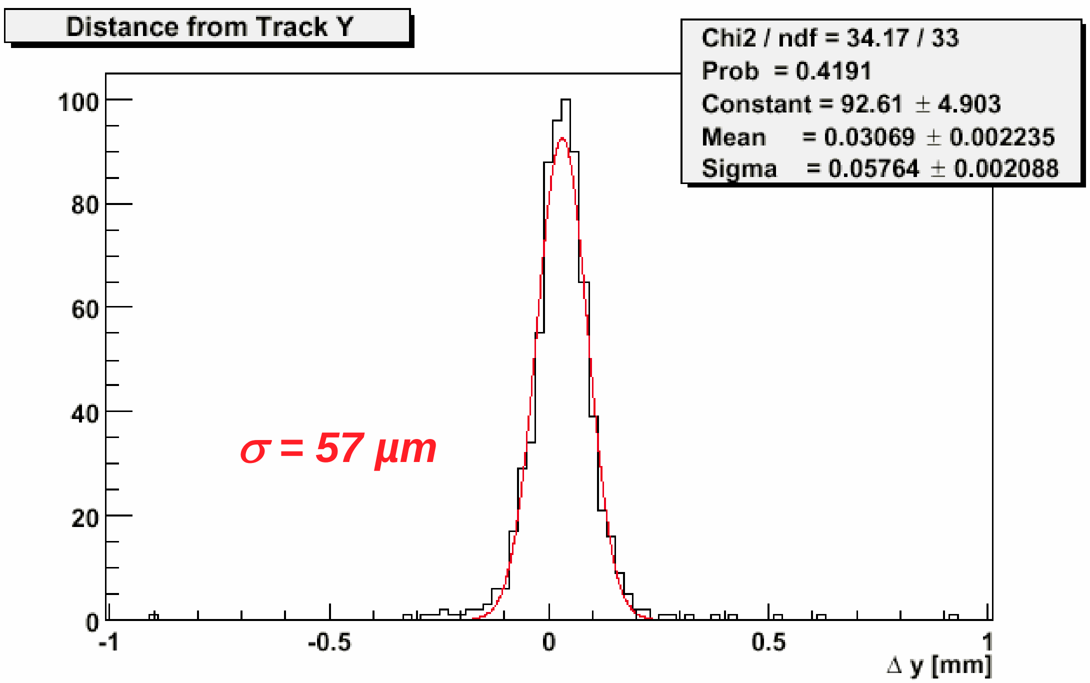
From F. Sauli presentation

SPACE AND TIME RESOLUTION

Time resolution:



Space resolution:



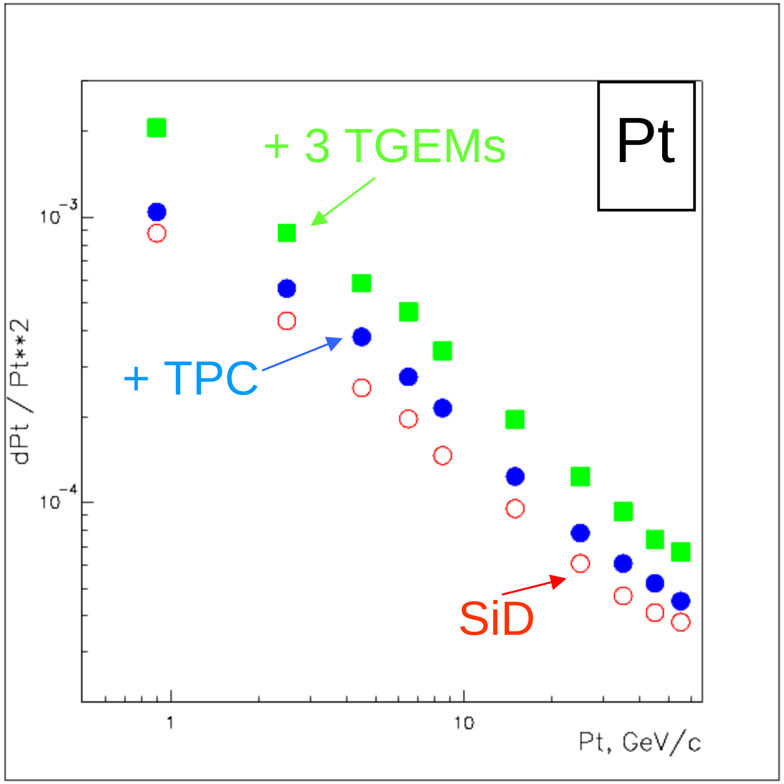
Traks fit with two TGEM and one silicon micro-strip
After deconvolution σ = 46±3 μm

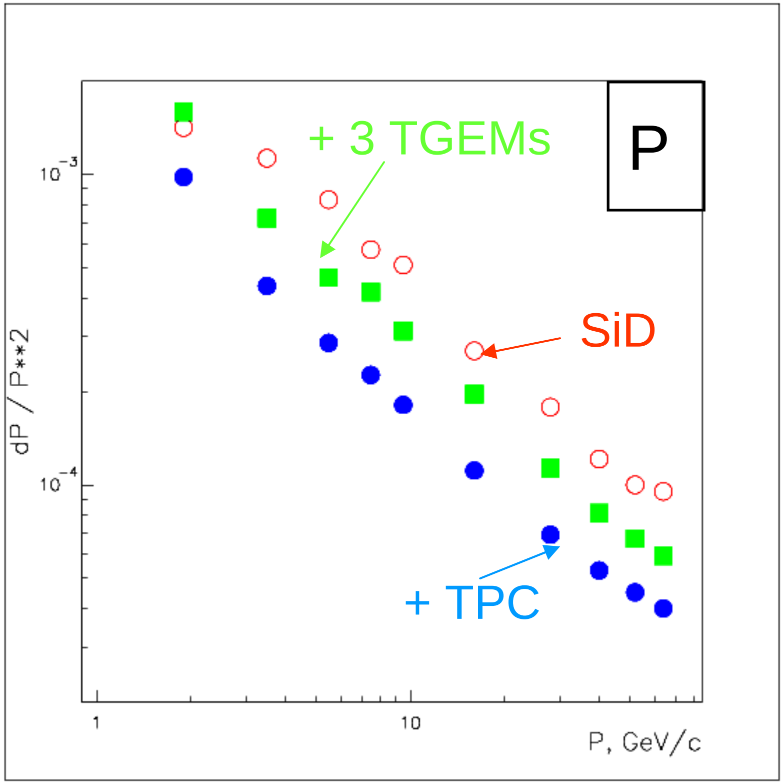
Time resolution: computed from charge signals in three consecutive samples (at 25 ns intervals)
σ = 12.4 ns

From F. Sauli presentation

Pt and P reconstruction performance

Barrel, $|\eta| < 0.9$, $\theta = \{ 45. – 135.\}$ deg

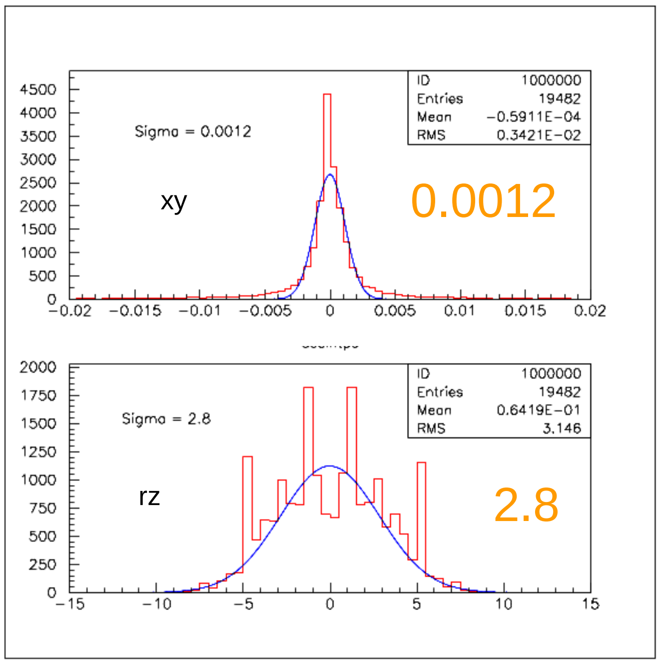




DCA to primary vertex position (impact parameter), xy and rz

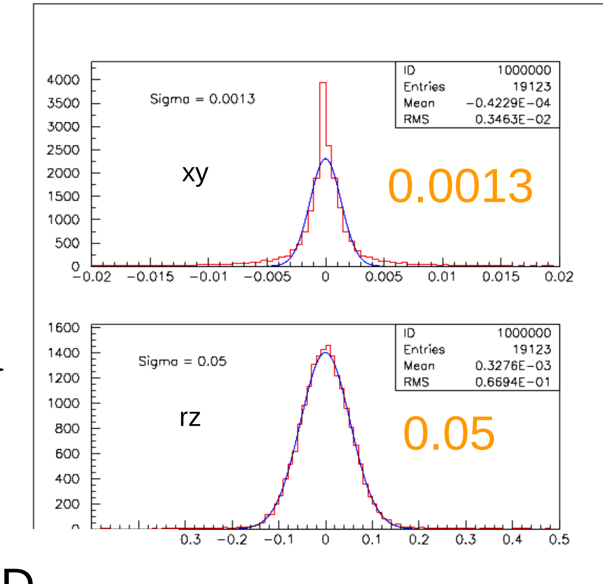
Barrel, |η| < 0.9, θ = { 45. – 135.} deg, Pt = {1. – 60.} GeV/c

SiD

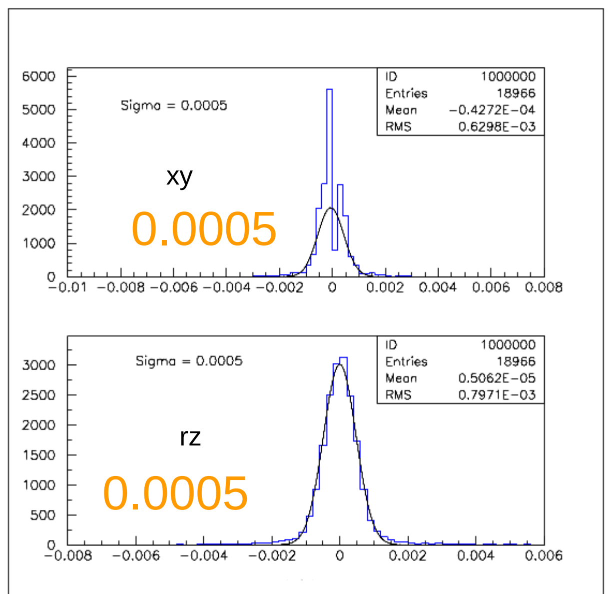


+ TPC

SiD + TPC



SiD (+ TPC) + VXD



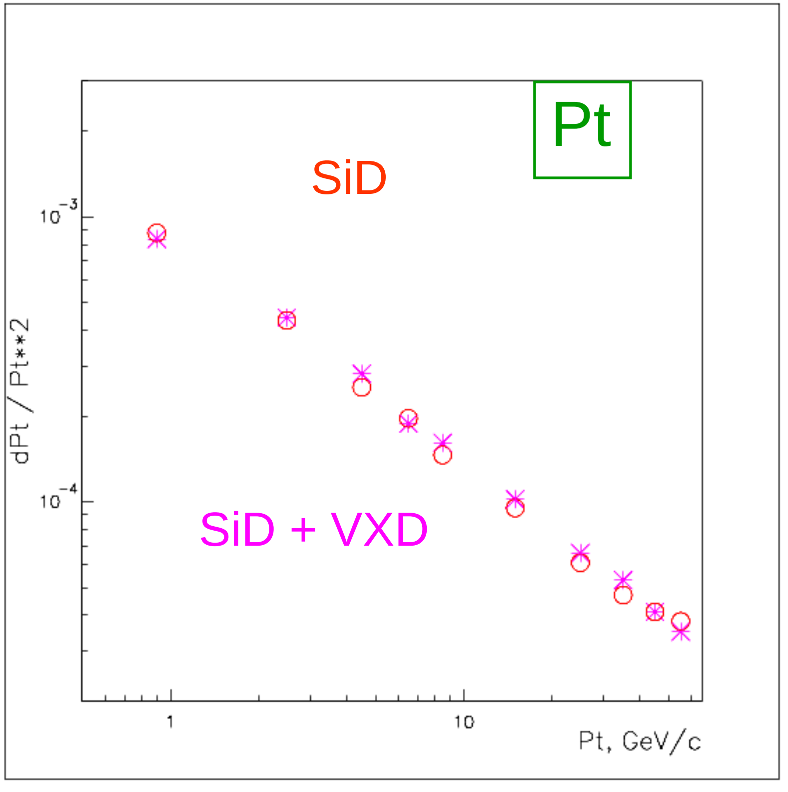
+ VXD

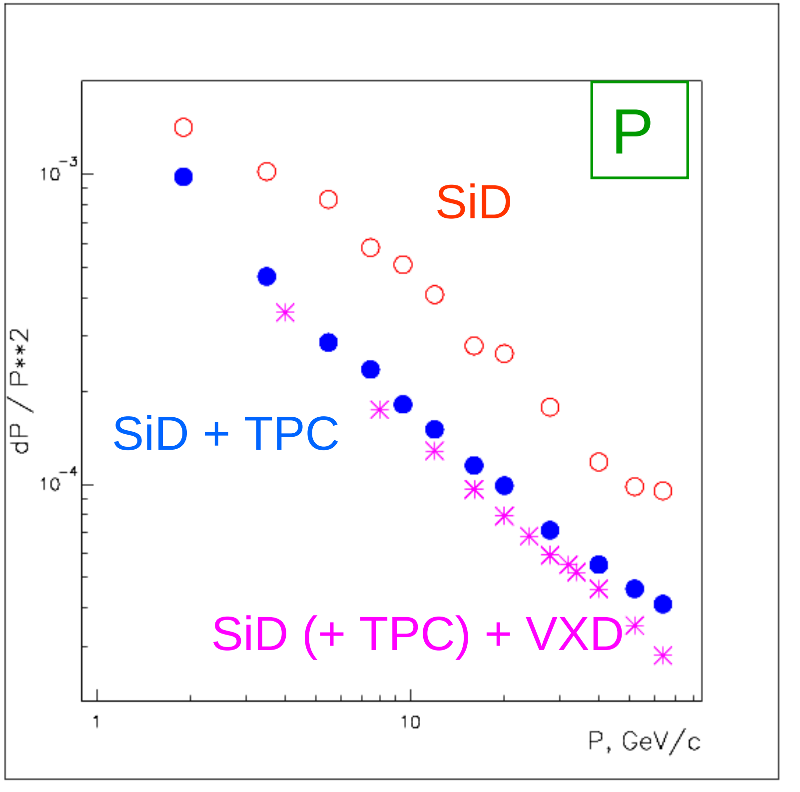
+ VXD

All numbers are in cm

+ VXD data

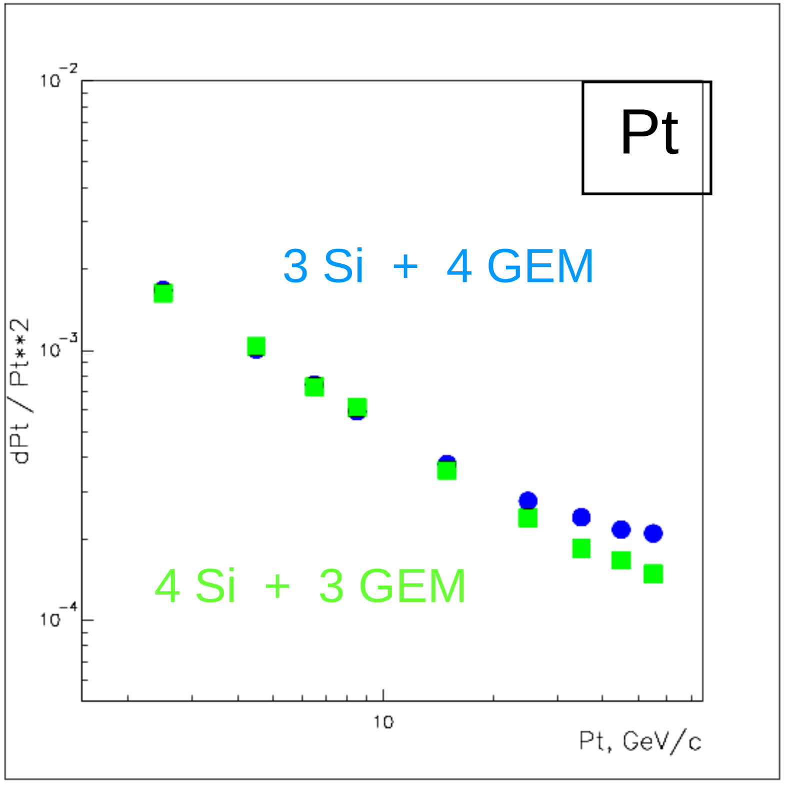
Barrel, |η| < 0.9, θ = { 45. – 135.} deg

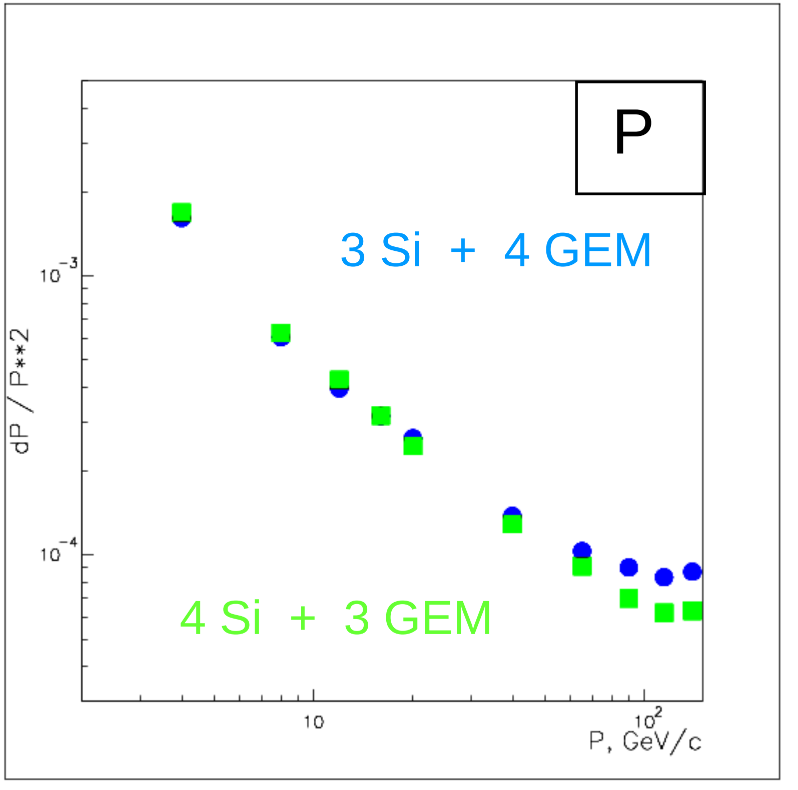




Pt and P reconstruction performance

Forward; |η| = {1.3 – 1.9}, θ = {17 – 30 } deg.





Instead of Conclusion

- There is a point to be discussed
- SiD + miniTPC is very powerful combination and can “solve all problems(!?)”
  - P reconstruction for both primary and secondary tracks
  - good matching with VXD and EMC
  - PID

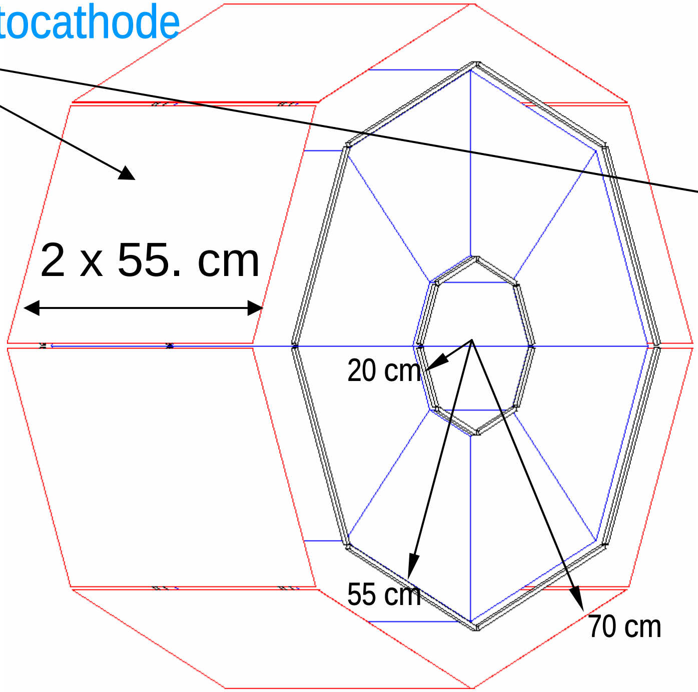
- Additional (or may be “main”) approach for track finding (Pt > ?):
  - TPC track finding: reliable and efficient
  - matching with Si-detectors data, re-fit
  - crossing with VXD, Calorimeters, μ-detectors
  - select VXD hits, re-fit, use VXD hits to reconstruct vertex (s)

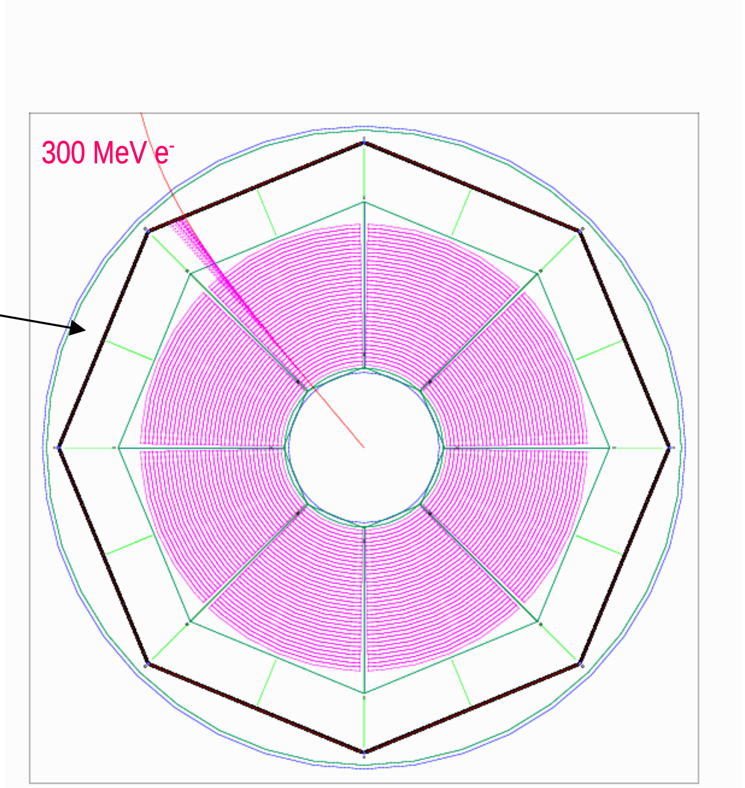
- Triple GEM Detectors with stereo-strips readout → Forward position
- miniTPC in Forward Direction ?
- low mass TPC construction with micropattern read-out should be demonstrated (R&D is in progress).
- GEM foil mass-production, test, calibration, passportization, ….

Fast, Compact TP with enhanced electron ID capabilities.

(R&D started)

Pad Detector with
CsI Photocathode





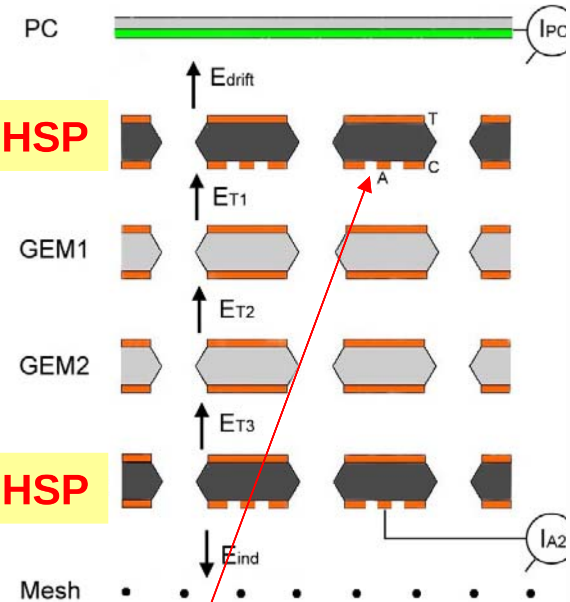
16 identical modules with 35 pad-rows,
Double (triple) GEM readout with pad size: 0.2x1. cm².
Maximum drift: 40-45 cm.
“Working” gas: fast, low diffusion, good UV transparency
(CF4 + X).

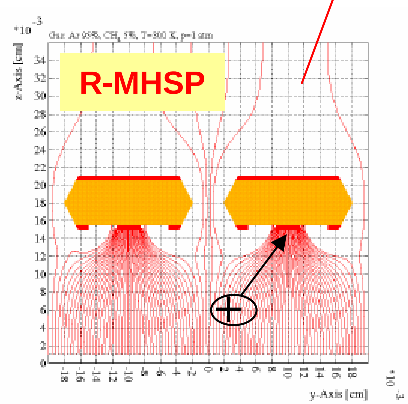
Ion back-flow reduction: reversed-MHSP & GEM

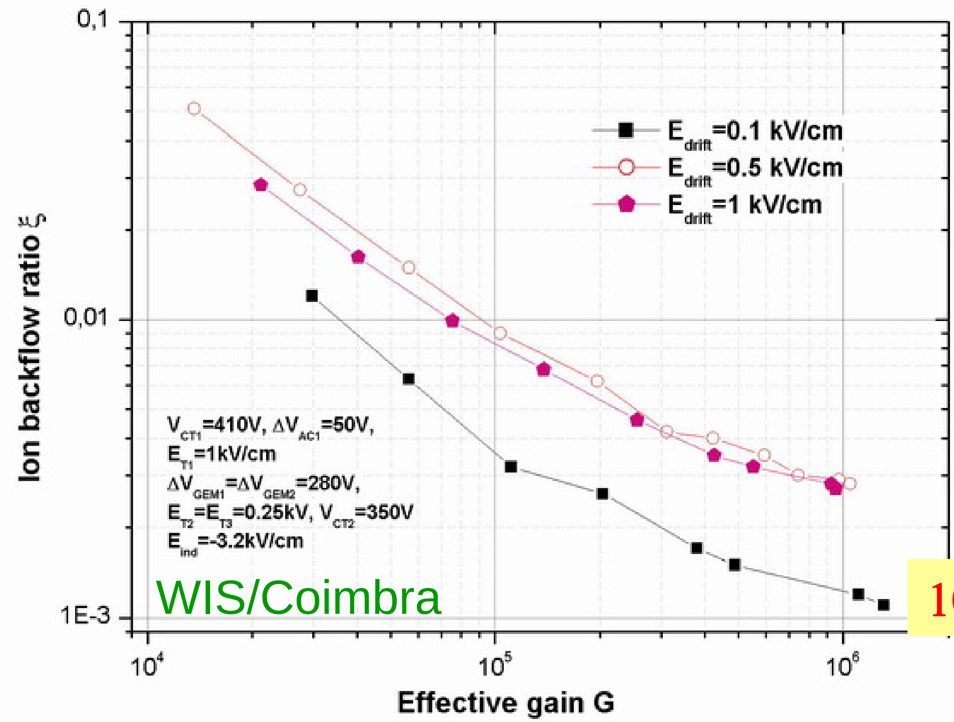
F. Amaro et al. WIS/Coimbra IEEE 2004

MHSP: gain & ion blocking
R-MHSP: ion defocusing*

* S.Roth, Vienna 04







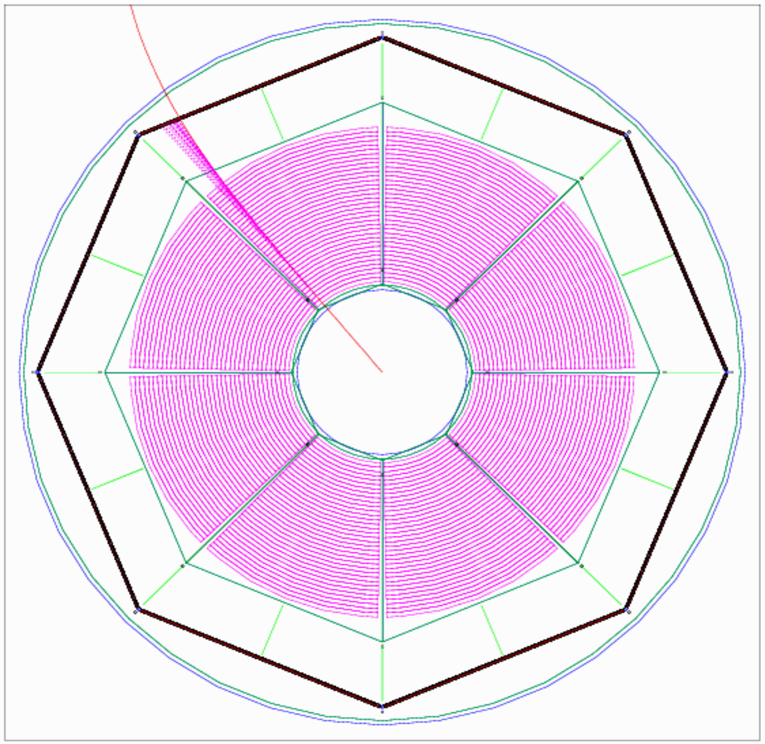
Multi-GEM: IBF = $10^{-1} – 2\ 10^{-1}$
Multi-GEM & MHSP: IBF = $2\ 10^{-2}$
R-MHSP & Multi-GEM & MHSP: IBF = **$1\text{-}3\ 10^{-3}$**

IBF: Ion Backflow Reduction

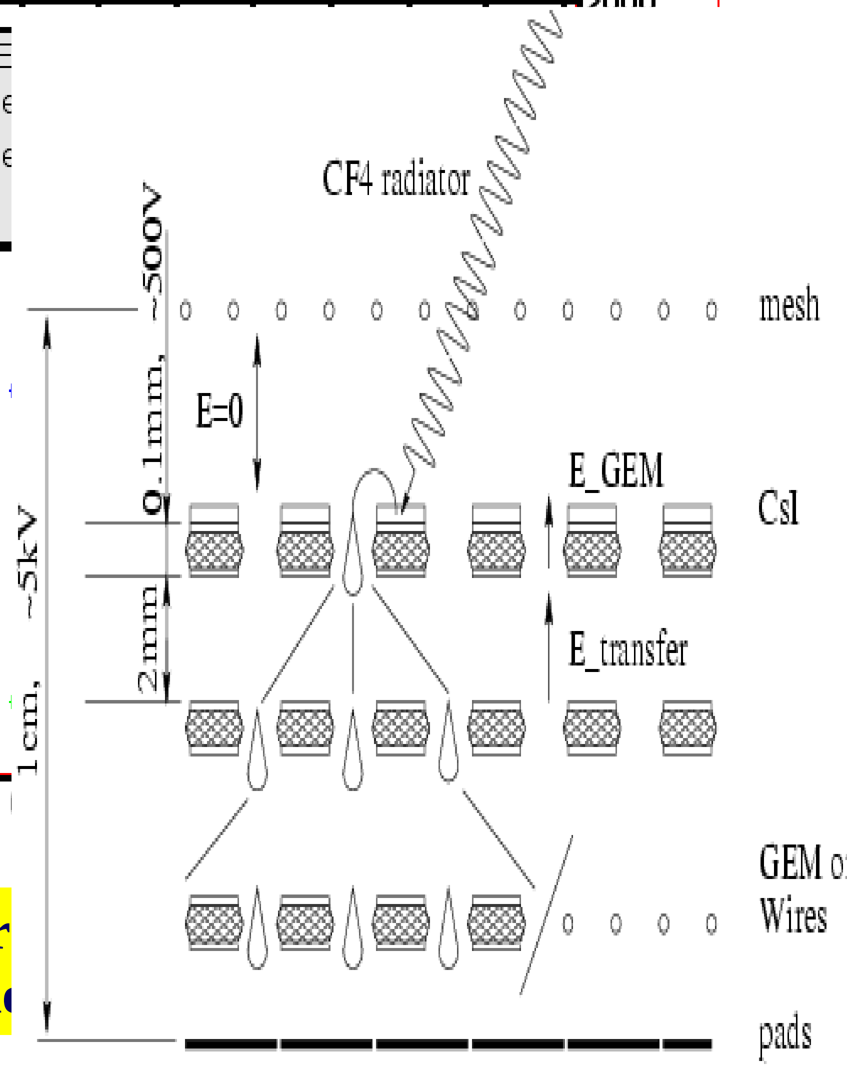
IBF R&D IN PROGRESS!

(Amos Breskin, WIS)

Hadron Blindness: UV photons vs. α particles



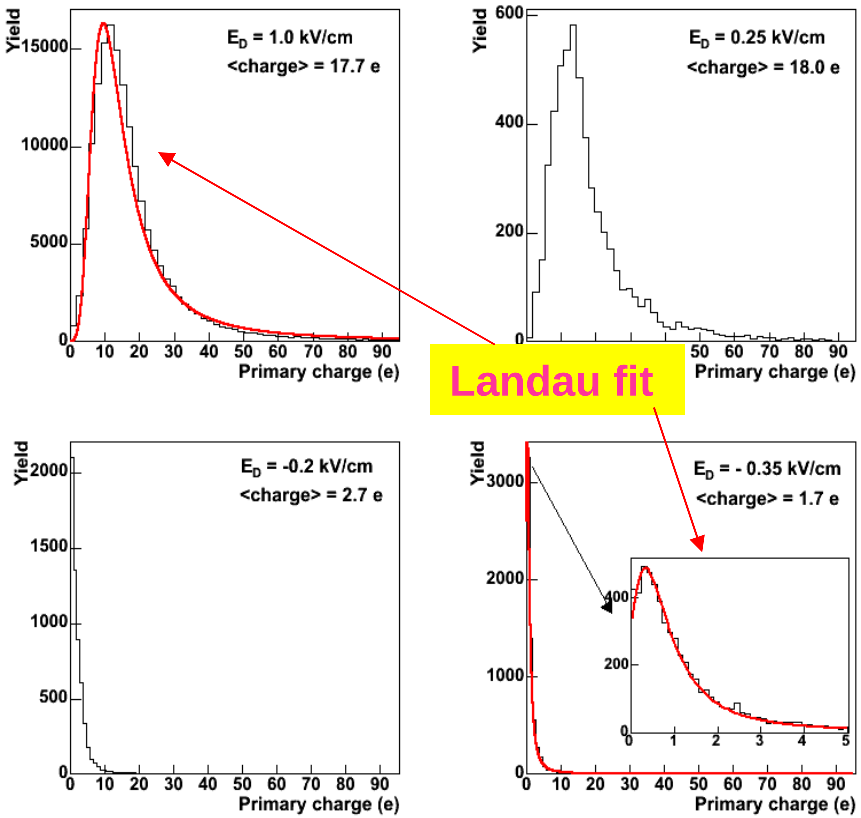
STAR upgrade / R&D proposal



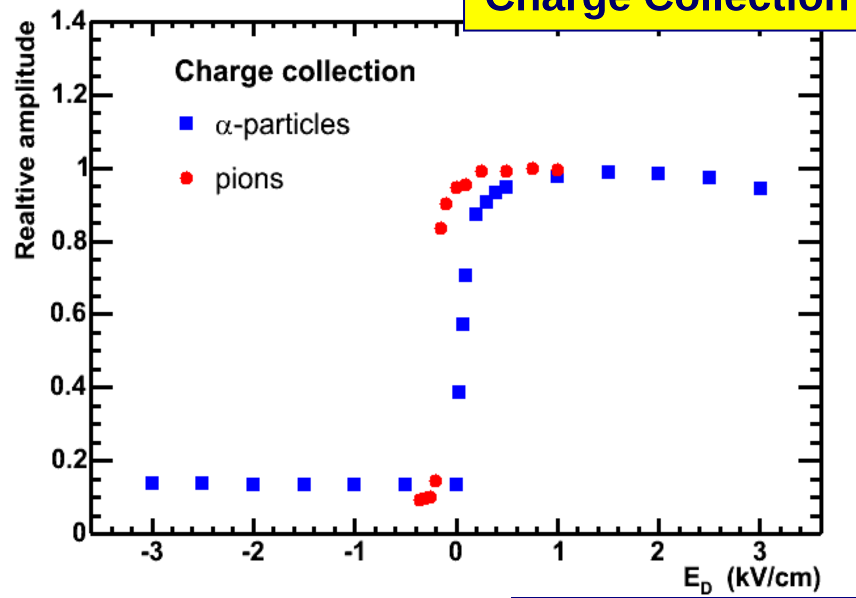
Hadron blindness: Response to hadrons

(KEK beam test)

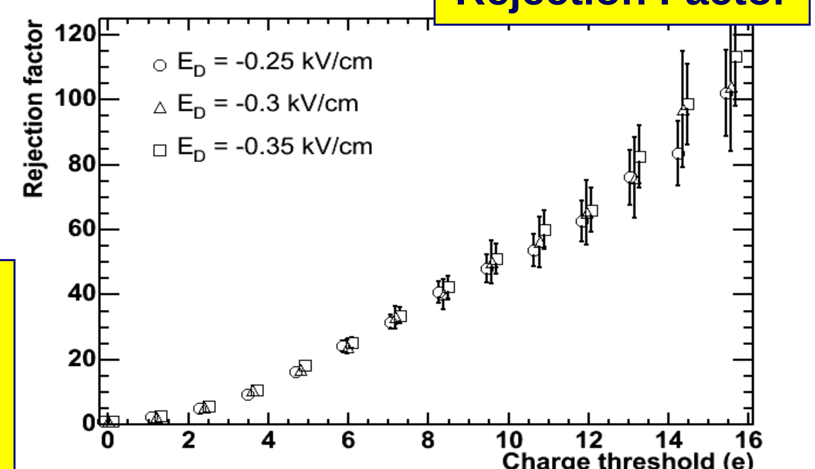
Pulse Height



Charge Collection



Rejection Factor

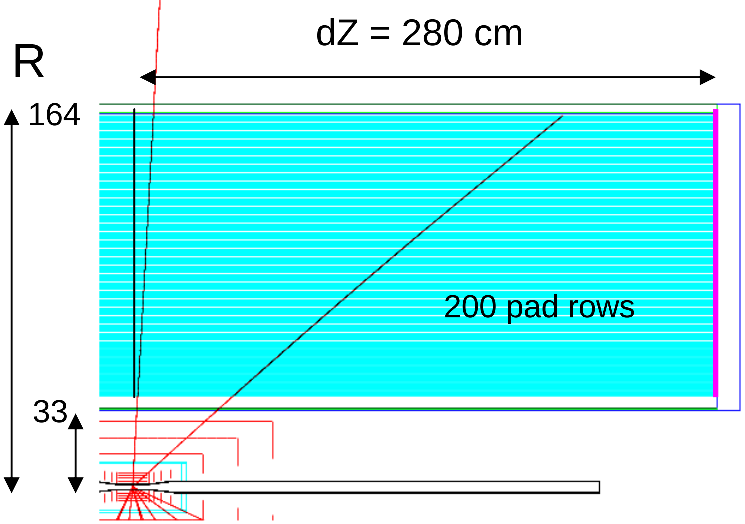


- **Pulse height strongly suppressed when E_D switches polarity**
- **Charge collected from 150µ layer above GEM**
- **Rejection factor limited by Landau tail**

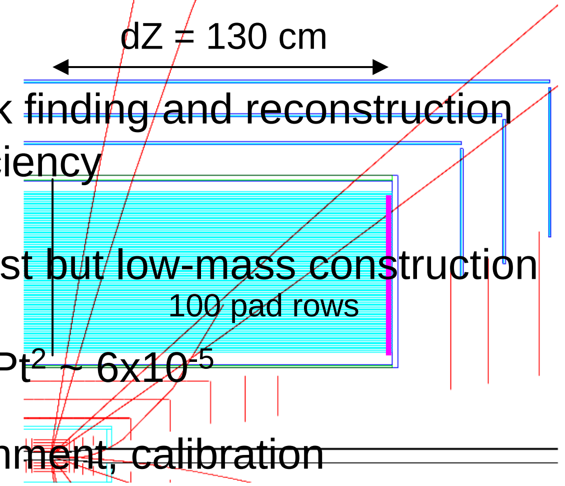
Future e+e- LC Detector Set-Up. Large TPC OR Middle one + Gas Micro-Pattern and Si pad (strip) detectors ?!

- is it realistic to get a hit space resolution ~100 μm for so long drift ?
- ExB corrections / alignment (Bz >= 4 T)
- space charge distortions; F(drift distance, time structure, fluctuations)
- field cage and construction materials thickness
- membrane (cathode) HV

Much easy to “struggle” with all mentioned problem (and cost);
but “low mass” construction with micro-pattern read-out approach for TPC should be proved



- track finding and reconstruction efficiency
- robust but low-mass construction
- $dPt/Pt^2 \sim 6 \times 10^{-5}$
- alignment, calibration

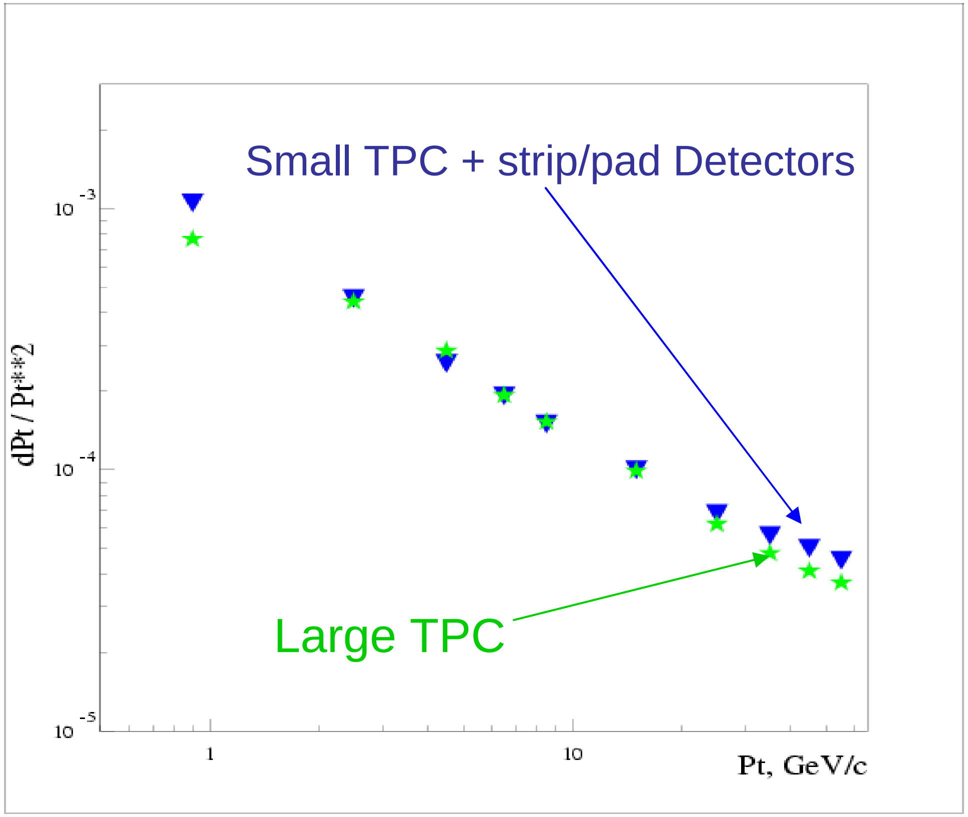


Gas micro-pattern strip (stereo) detectors demonstrated very good performance
Low mass (and cost), fast, reliable, with space resolution ~40 μm
Convenient for alignment; TPC calibration and corrections, events pile up;
trigger possibilities (?!)

Two variants, Pt reconstruction performance comparison

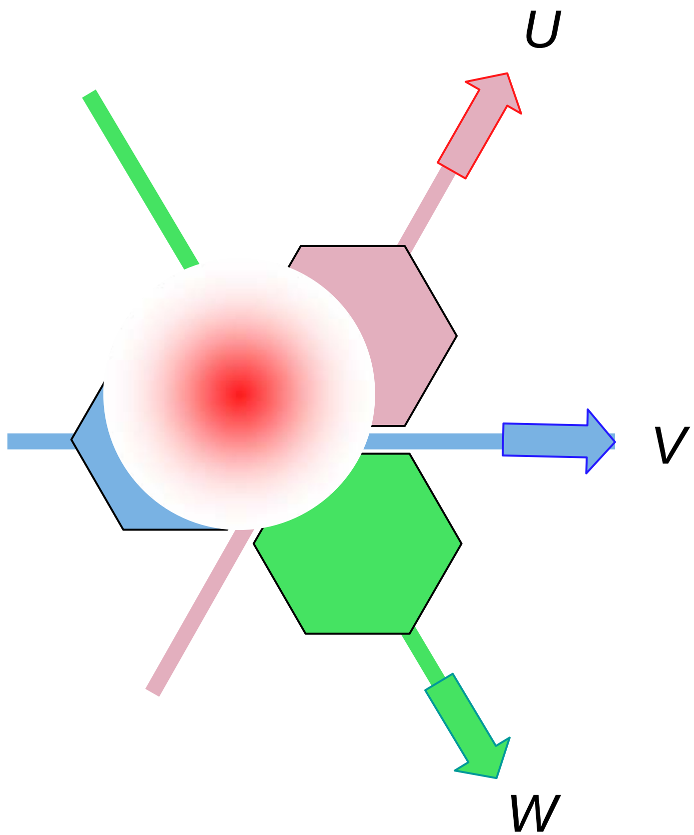
(realistic thickness, GEANT, hit Gaussian smearing, Helix fit)

Rapidity = (+/- 0.8), Bz = 5 T



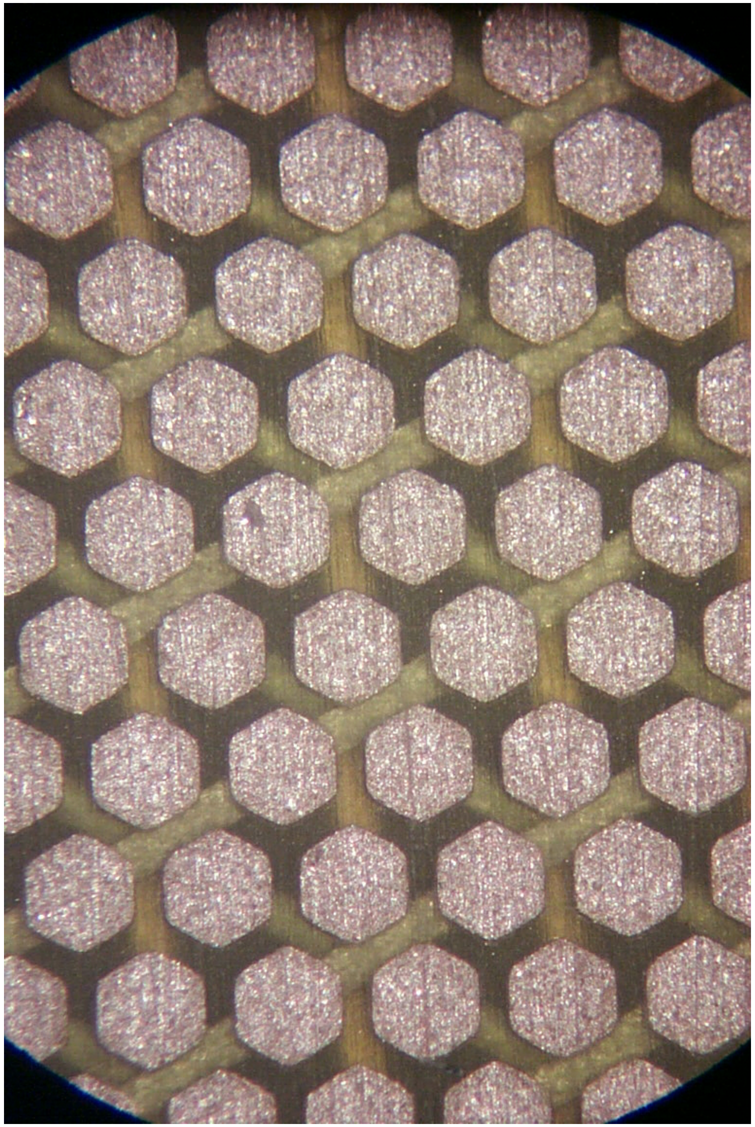
	$\sigma_{r\varphi}$	σ_z (μm)
TPC (Ar+CF4)	100.	300.
GEM (strip stereo)	50.	700.
Si (strip stereo)	20.	600.
Si (vertex) (20x20 μm² pads)	5.	6.

Hexaboard readout: matrix of hexagonal pads
interconnected along three projections at 120º



S. Bachmann et al
Nucl. Instr. and Meth. A 478 (2002) 104

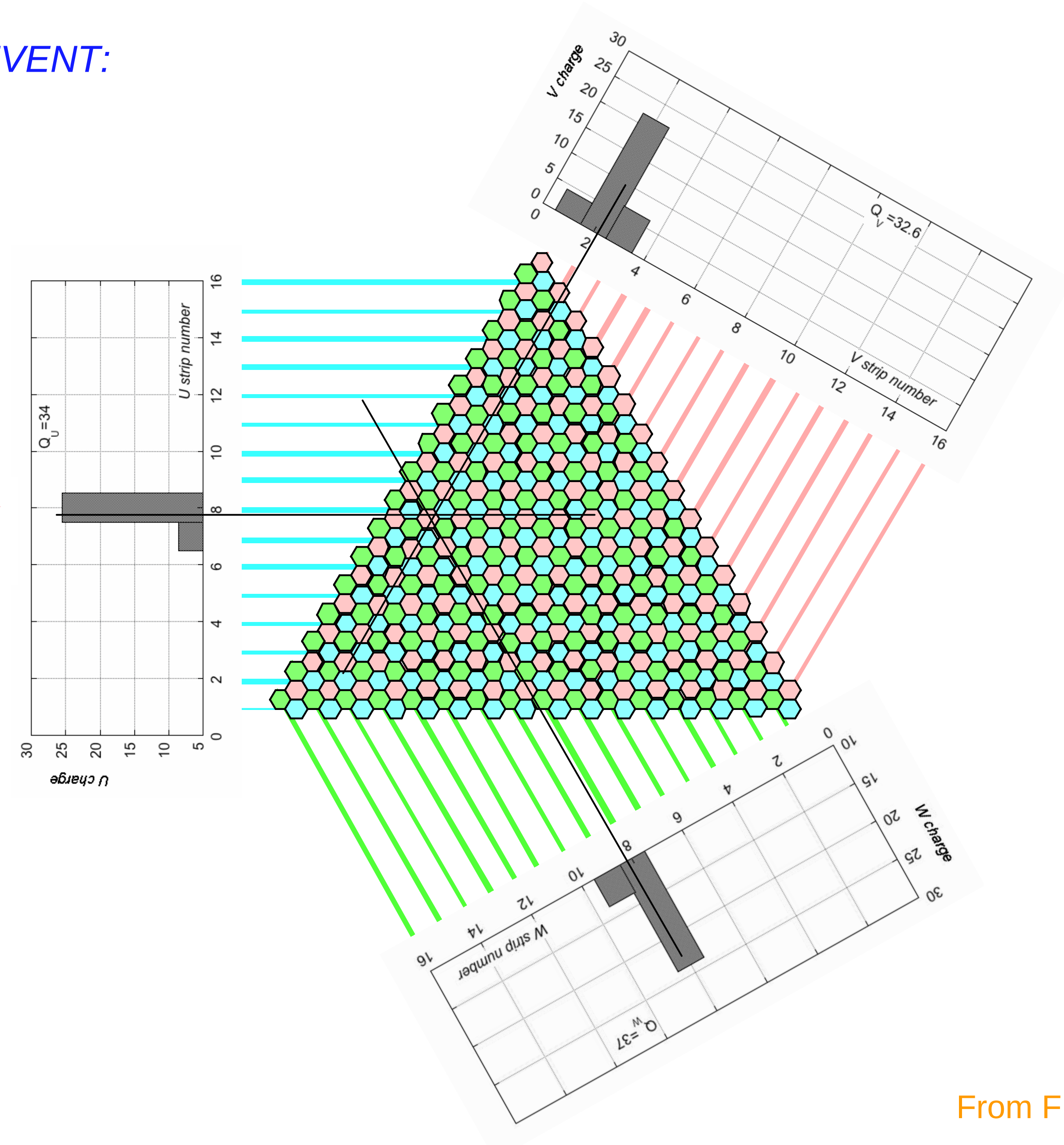
Hexaboard closeup: 520 µm Ø pads



From F. Sauli presentation

SINGLE EVENT:

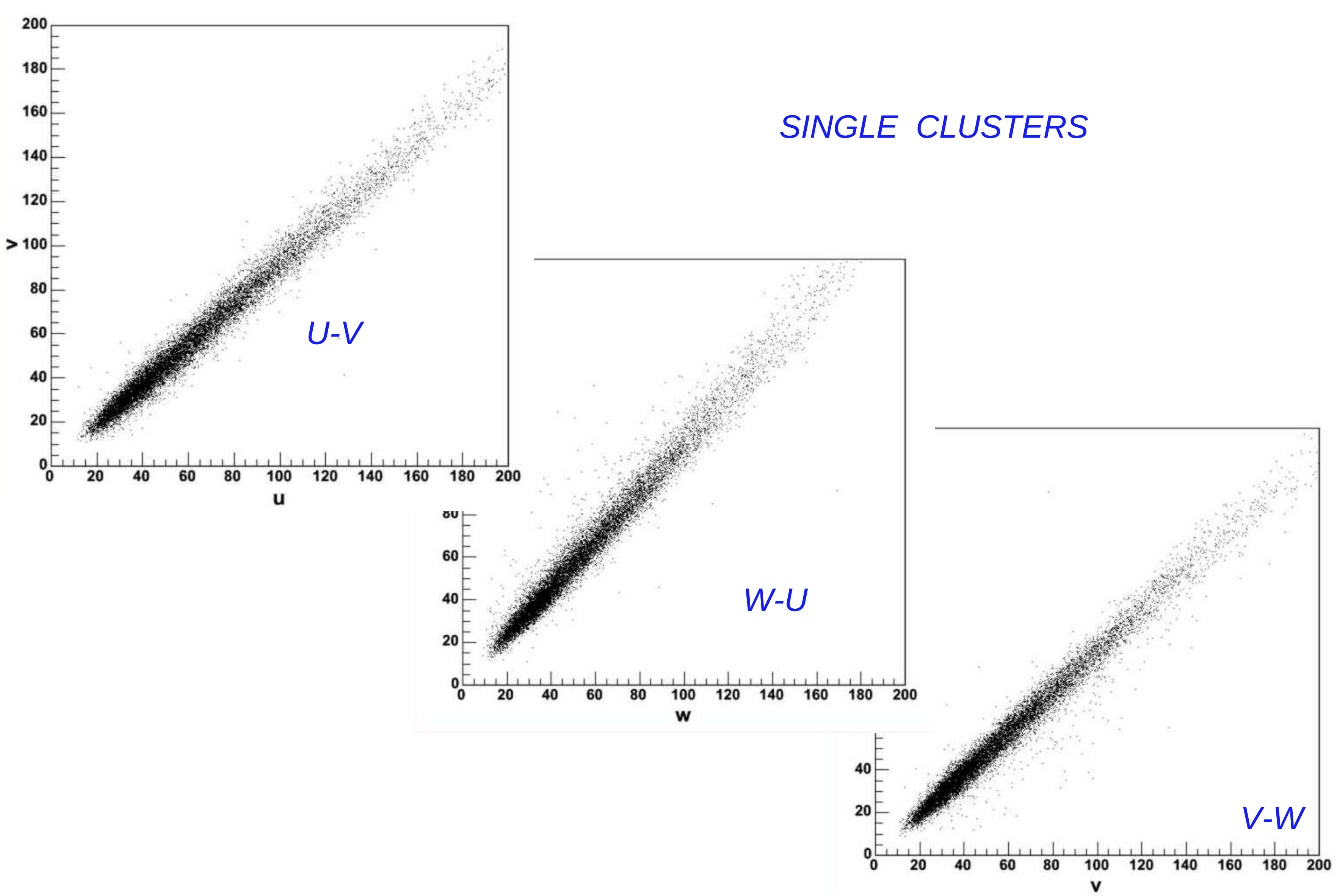
16 strips
8.3 mm



From F. Sauli presentation

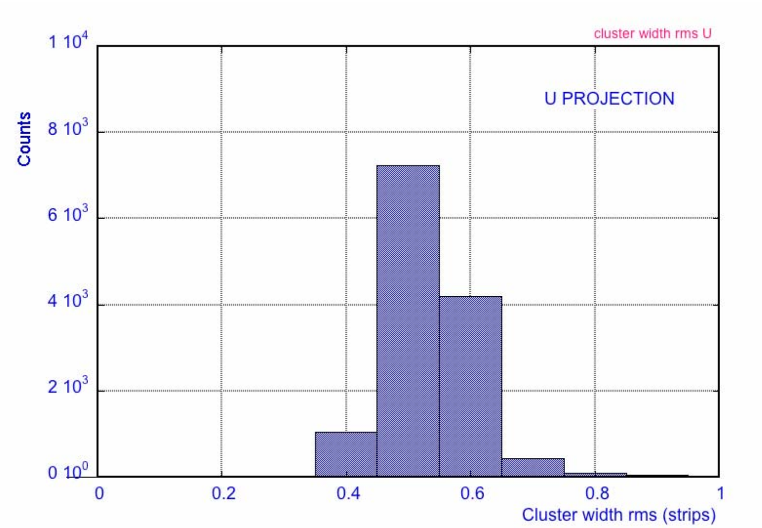
CHARGE CORRELATION BETWEEN THE PROJECTIONS:

SINGLE CLUSTERS



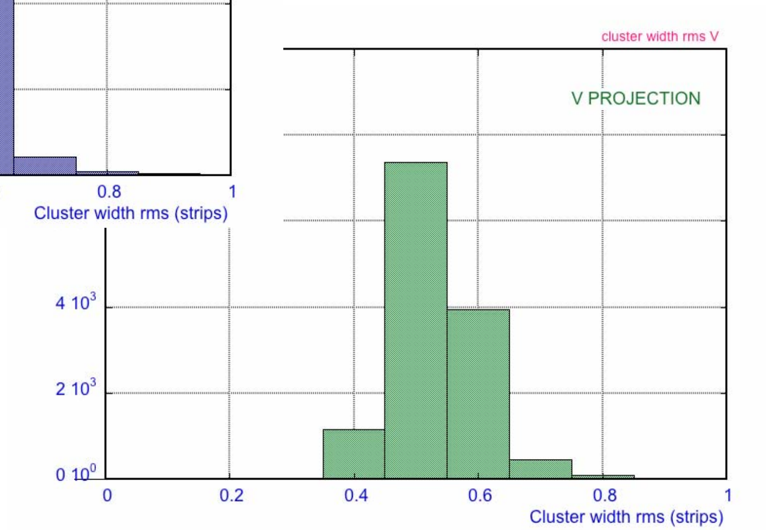
From F. Sauli presentation

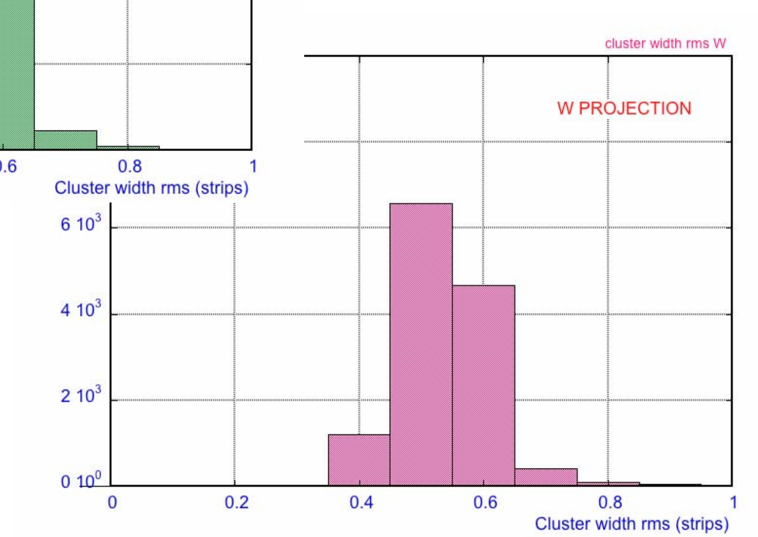
SINGLE PHOTON CLUSTER WIDTH (rms)



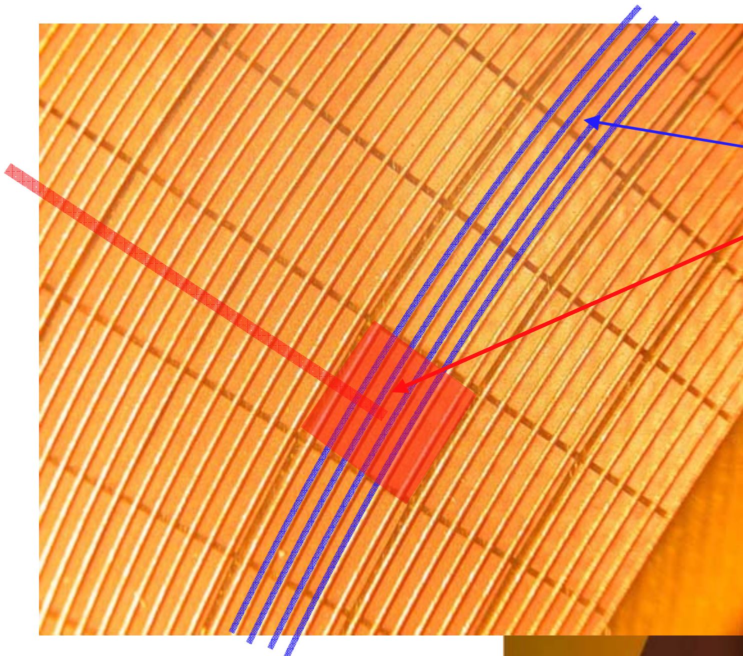
σ~ 250 µm

Charge sharing (520 µm pad rows)





From F. Sauli presentation

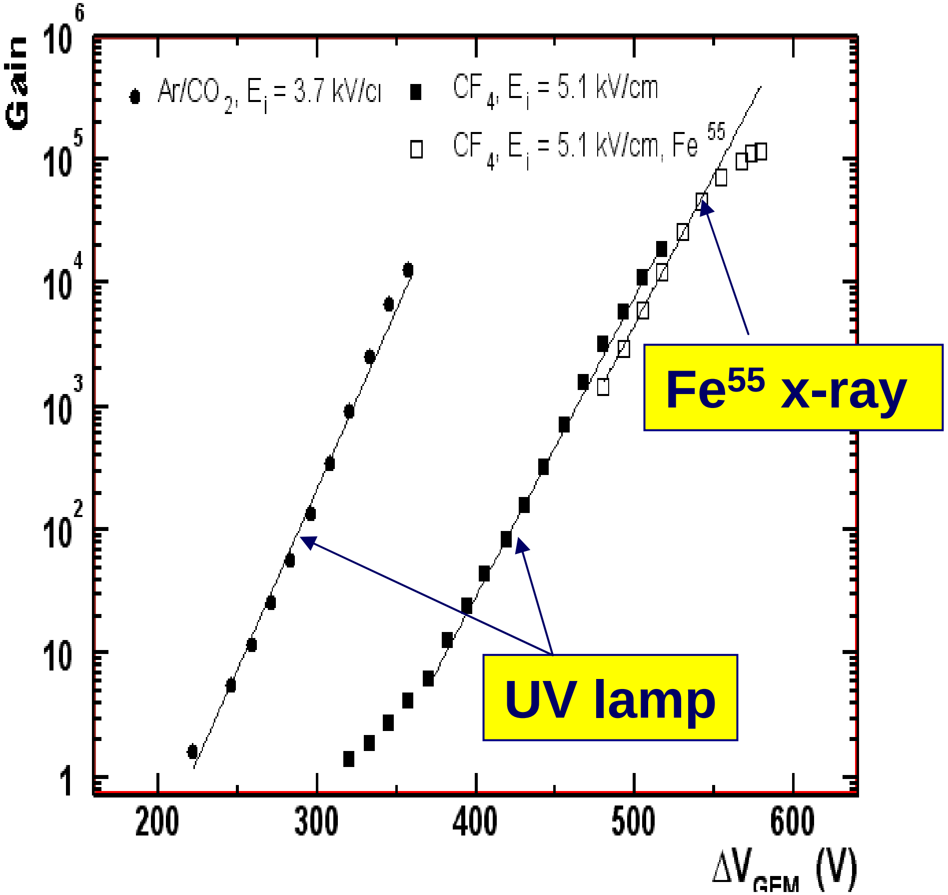


TOTEM READOUT BOARD:
Radial strips (accurate track's angle)
Pad matrix (fast trigger and coarse coordinate)

From F. Sauli presentation

Gain Curve: Triple GEM with CsI in CF_4:

measured with Fe^{55} and with UV lamp



- **Gains in excess of 10^4 are easily attainable.**
- **Voltage for CF_4 is ~140 V higher than for Ar/CO_2 but slopes are similar for both gases.**
- **Gain increases by factor ~3 for ΔV = 20V**
- **Pretty good agreement between gain measured with Fe55 and UV lamp.**

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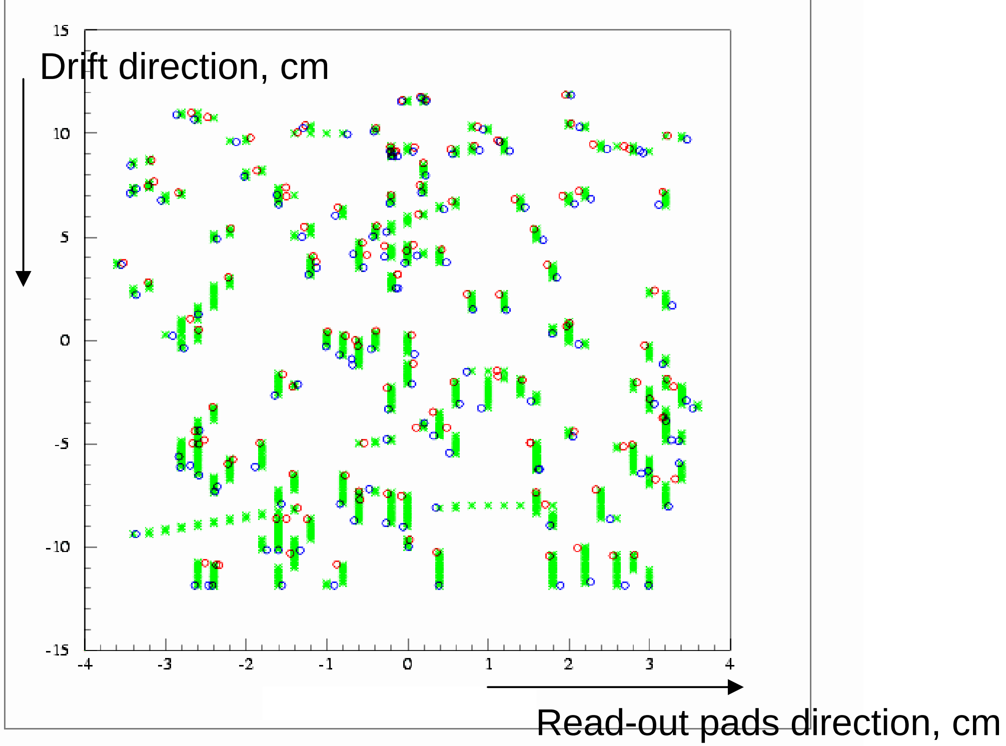
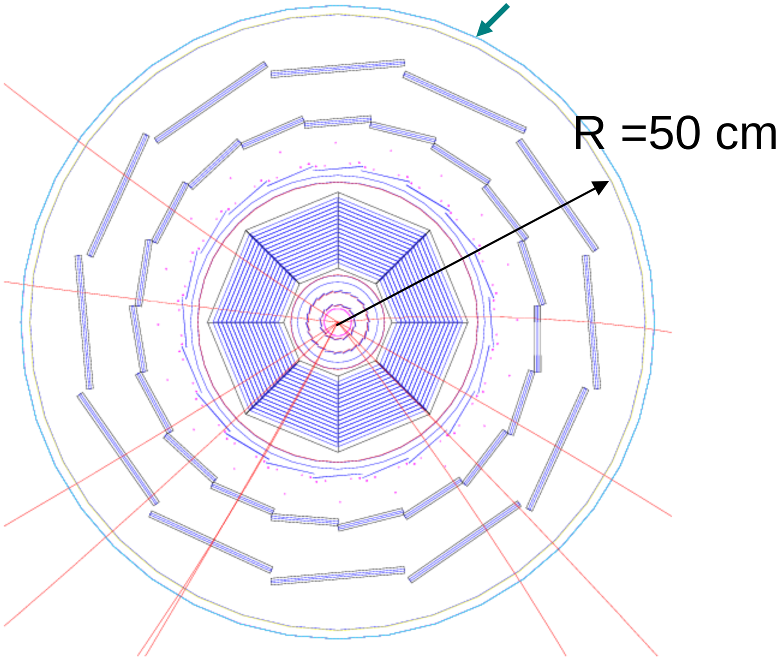
STAR tracking upgrade. Possible variant with μTPC

(fast, low diffusion gas mixture; micropattern read-out; low-mass construction)

Central HJ event, miniTPC response simulation, first (in R) pad-row



STAR TPC In-Field_cage



VXD in GEANT